2003

The effect of various protein ingredients utilized as a lean meat replacement in a model emulsion system and frankfurters

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The effect of various protein ingredients utilized as a lean meat replacement in a model emulsion system and frankfurters

by

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A dissertation submitted to the graduate faculty

in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

Co-majors: Meat Science; Food Science and Technology

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Ames, Iowa

2003

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DEDICATION

This dissertation is dedicated to my family, friends, and professors whose unwavering support allowed me to make the most of today and look with hope toward tomorrow.

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ACKNOWLEDGEMENTS

Although the struggle to obtain my Ph.D. is a personal achievement, I feel as though this accomplishment would not be possible if it wasn't for the efforts of other individuals who have made an impact on my life thus far. In the next few pages I hope to properly recognize and acknowledge those individuals that have made this journey toward my advanced degree a success.

A sincere thanks to my family. My parents, Joe and Barb Wenther, deserve most of the credit for the accomplishments of their children. They instilled a strong foundation of values, work ethic, dedication, and common sense. Although it may have seemed that I was unresponsive to advice at times, everything worked out and obstacles were always overcome. To my two older brothers and their families, thank you for all of your support. I hope you have finally found comfort in the answer to that nagging question you always asked me, "So when are you going to be done with school?"

There have been many individuals who have made an impact on my academic career at Iowa State University. I would like to begin by thanking Dr. Joseph Cordray, my academic advisor, for all of his support, encouragement, advice, guidance, and friendship throughout the years. Dr. Cordray has educated me on much more than meat science and processed meat production. Dr. Cordray has taught me about the "little things" that make big impressions on customers and colleagues within the meat industry. I also appreciate all of the opportunities that he has given me to travel around the country educating other meat processors, educating myself, and creating lasting friendships in the meat industry. Selecting Dr. Cordray as my major professor was one of the best choices I made after

arriving at Iowa State University. His guidance is the benchmark that all future supervisors will be judged against.

I would like to thank the other members of my graduate committee. I thank Dr. Jane Love for being my co-major professor so that I could receive my Food Science and Technology degree. I also appreciate the time and effort put forth by she and her staff for the sensory panel section of my project. Dr. Joe Sebranek deserves recognition for his support inside and outside of the classroom, as well as the stimulating topics he generated through conversations and publications. To Bob Rust, thank you for the "behind the scenes" education throughout the short courses and projects conducted at the Iowa State University Meat Laboratory. I appreciate the time and statistical guidance Dr. Philip Dixon gave me throughout my project. His statistical advice on the organization and analysis of the data was crucial to the success of this project.

I would like to recognize the Iowa State University Meat Laboratory staff and student employees for all of the assistance provided to me throughout my project and other endeavors that I took part in at the Meat Laboratory. The working environment that has been established at the Meat Laboratory over the years makes going to school/work each day a bearable experience.

Special gratitude is due to Terry Houser for being a good friend and academic colleague – a relationship that will continue to expand in future years. To all fellow graduate students, thank you for the help and the friendships that have generated fond memories; everything was greatly appreciated and a necessity for the completion of my degree. I wish nothing but the best for all as they persevere through their personal lives and academic careers. Try not to be consumed by the academic machine; use your

education as a platform of knowledge while applying your imagination and individuality as a means to solve problems that arise throughout your careers.

On a more personal note, I sincerely appreciate the support given to me by my fiancée, Allison L. Riddle. Allison, I appreciate the effort you have put forth to deal with my stubborn streak and the attempts you made to demonstrate to me that there are more important things to life than work. I am still amazed that I traveled so far in my educational career, from state to state, only to find a girl that has been so close to me (physically and emotionally) my entire life.

I would like to express my gratitude to Proliant Inc., and more specifically Dave Hull, Gits Prabhu and Darin Doerscher, for the opportunity to work with their lean meat replacement systems. Proliant Inc. and its employees have given more than funding to this project. They have given me an educational opportunity to learn more about collagens, project guidance, and provided an "open door" approach to education.

In conclusion, I am reminded of the lyrics from Frank Sinatra's song "I Did It My Way":

> *And now the end is near and so I face the final curtain*
> *My friends, I'll say it clear, I'll state my case at which I'm certain*
> *Regrets, I've had a few, but then again to few too mention*
> *I did what I had to do and saw it through without exemption*
> *I planned each charted course, each careful step on the bi-way*
> *And more, much more than this, I did it my way.*

Once again, thank you to all for the support and encouragement that made this dissertation possible.

CHAPTER 1. GENERAL INTRODUCTION

Through the years, the meat industry has seen the production of healthier food products due to the demands of the health conscious consumer. Non-meat ingredients intended to reduce the final product fat content are generally referred to as fat replacers. Starches, konjac flour, carrageenan, and xanthan gum are a few of the commonly utilized ingredients to reduce fat in processed meat products. In past years, collagens have been utilized in reduced/low fat products such frankfurters and bologna (Delmore and Mandigo 1994; Calhoun and others 1996; Osburn and others 1999). Unfortunately, a majority of consumers are unwilling to sacrifice product quality or eating characteristics for the consumption of reduced fat products, which in turn created a plateau or leveling effect in the production and purchasing of reduced fat food products.

Currently, the United States Department of Agriculture (USDA 2002) has the standards of identity or composition of frankfurters outlined in Title 9, Chapter III, Part 319, Section 319.180a. The definition states that "frankfurters must be prepared from one or more kinds of raw skeletal muscle meat, seasoned and cured. The frankfurters may or may not be smoked and the finished product shall not contain more than 30 percent fat. Water and/or ice may be used to facilitate chopping/mixing or to dissolve the curing ingredients. The frankfurter shall not contain more than 40 percent of a combination of fat and added water."

While meat-like ingredients prefabricated from protein sources (i.e. vegetable proteins, etc.) continue to increase in cost, it has been desirable to research the potential for making edible meat products from the substantial amounts of animal proteins (e.g. animal skin) which are currently under-utilized. As world population and consumption of

food products increases, the uses of alternative protein sources (i.e. collagens, plasmas, etc.) are being explored in an attempt to replace a portion of the lean meat utilized in the production of processed meat products. Collagen is present in comminuted meats and meat products either as a natural component of the connective tissue of the meat used in the process or as an additive. Many processors may replace a portion of the lean with water to alleviate the cost of production. Final product characteristics such as flavor, texture, mouth-feel, and juiciness cannot be surrendered at the cost of reducing the skeletal tissue amount in processed meat products.

Sadler and Young (1993) compared the sensory and textural parameters of sausages produced with a portion of the lean replaced by raw or preheated beef tendon. Panelists determined that sausages with precooked tendon were always more desirable in texture, flavor, and acceptability than sausages with raw tendon. Osburn and others (1997) utilized flaked pork skin in the production of gels that were incorporated in low-fat bologna formulations. The authors found that the gels improved water-binding properties and enhanced sensory characteristics by reducing hardness and increasing juiciness.

Protein functionality is a general term that has been defined as, "any physicochemical property that affects the processing and behavior of protein systems as judged by the quality attributes of the final product" (Kinsella 1976). The sensory characteristics have often correlated highly with corresponding instrumental attributes in meat products (Lyon and others 1980; Meullenet and others 1994). Tenderness is a critical attribute for quality of meat and meat products. Tenderness and hardness are inversely related. Both sensory and instrumental hardness, springiness and cohesiveness are primary mechanical parameters that can be used to characterize the texture properties of sausage. Juiciness measures the amount of expressible water of sausage.

The overall objective of this research was to investigate the use of protein ingredients (e.g. gelling plasma and various collagens) in a model emulsion system and frankfurters. Three phases of research were conducted to achieve the objective. The first phase (1) compared gelling plasma and various collagens in a model emulsion system using only meat, fat, salt, water and the treatment ingredient provided by Proliant Inc. Processing attributes such as yield, water separation, fat separation, raw pH, and cooked pH were measured on centrifuge tube samples. Proximate composition (water, fat, protein, and ash) was measured on cooked centrifuge samples. Texture attributes were measured by puncture analysis and texture profile analysis on a variety of different samples (e.g. centrifuge tube, centrifuge tube core, frankfurter-skin on, and frankfurter-skin off). In an attempt to produce an emulsion that was more representative of a true frankfurter emulsion, the second phase (2) was designed. The second phase was conducted as characterized by the first phase with the addition of spices, sodium erythorbate, sodium phosphate, and curing salt (6.25 percent sodium nitrite) to the formulation. The same processing attributes, proximate composition, and texture attributes were measured as well as color analysis (Hunter L*, a*, and b*). Measurements were taken on centrifuge tube samples depending on recorded measurement. The third phase (3) was the commercial production of frankfurters using the formulations from phase 2. The same processing attributes, proximate composition, and texture attributes were measured. Measurements were taken on frankfurter samples depending on recorded measurement. The correlation between the model emulsion system and frankfurter system was researched. Furthermore, the similarity between the control and treatment samples was determined.

Dissertation Organization

This dissertation is organized into eight chapters. The first chapter is a general introduction to the use of collagens in processed meat products. The second chapter is a general literature review of relevant topics pertaining to this research project. The third chapter describes the materials and methods used in each phase of this research. The fourth chapter is a manuscript of preliminary research (Phase 1) that contains an abstract, introduction, materials and methods, results and discussion, conclusion and references. The fifth chapter is a manuscript of the model emulsion system (Phase 2) and the frankfurter system (Phase 3). The formulations and treatments are the same for both phases. The manuscript contains an abstract, introduction, materials and methods, results and discussion, conclusion and references. The sixth chapter is a manuscript on the commercial production of frankfurters containing poultry protein ingredients (e.g. chicken or turkey collagen) at varied levels as a replacement to a portion of the lean used in the formulations. This manuscript also contains an abstract, introduction, materials and methods, results and discussion, conclusion and references. The seventh chapter is a general summary of this research.

References

Calhoun CM, Eilert SJ, Mandigo RW. 1996. Characteristics of low-fat, high-added-water frankfurters manufactured with preblends of connective tissue and alkaline phosphates. J. Muscle Foods. 7(4):471-487.

Delmore RJ, Mandigo RW. 1994. Modified pork connective tissue for use in low-fat high added water frankfurters [abstract]. In: IFT Annual Meeting Book of Abstracts; 1994 June 25-29; Atlanta, GA. Chicago, IL.: Institute of Food Technologists. Abstract nr 47D-27.

Kinsella JE. 1976. Functional properties of proteins in foods: A survey. CRC Crit. Rev. Food Sci. Nutri. 7(3):219-280.

Lyon CE, Lyon BG, Davis CE, Townsend WE. 1980. Texture profile analysis of patties made from mixed and flake-cut mechanically deboned poultry meat. Poultry Sci. 59: 69-76.

Meullenet JF, Chang HC, Carpenter JA, Resurreccion AVA. 1994. Textural properties of chicken frankfurters with added collagen fibers. J. Food Sci. 59: 729-733.

Osburn WN, Mandigo RW, Calkins CR. 1999. Utilization of desinewed beef connective tissue gel in reduced-fat bologna. J. Muscle Foods. 10(1):29-50.

Osburn WN, Manidgo RW, Eskridge KM. 1997. Pork skin connective tissue gel utilization in reduced-fat bologna. J. Food Sci. 62(16):1176-1182.

Sadler DHN, Young OA. 1993. The effect of preheated tendon as a lean meat replacement on the properties of fine emulsion sausage. Meat Sci. 35(2): 259-268.

United States Department of Agriculture. 2002. Code of Federal Regulations. Citation 9CFR319.180a (http://www.usda.gov). United States Department of Agriculture. Washington, DC.

CHAPTER 2. REVIEW OF THE LITERATURE

Introduction

Meat processing had its origin before the dawn of civilization. Although world meat production has surged nearly fivefold since 1950, growing from 44 million tons to 211 million tons in 1997, an estimated one in every six people goes hungry each day in the world. Global meat consumption is dominated by the United States, China, Brazil, and the European Union. These countries consume over 60 percent of the world's beef, over 70 percent of the world's poultry, and over 80 percent of the world's pork (Anonymous 1998).

The population is rising at 1 percent per year in developed countries and 2.5 percent in developing countries, and the projected world population for the year 2000 was six billion (Finley and Price 1994). According to the public library's homepage (www.ibiblio.org 2003) the current world population is approximately 6.3 billion people. As populations continue to grow worldwide and meat prices continue to increase, utilizing alternative proteins in processed meats to directly replace meat proteins become increasingly promising.

In most places where non-skeletal meats and other tissues are used in processed meats, the primary motivation is usually economics. With relatively low consumer purchasing power, coupled with the high price of skeletal muscle meats, processors are driven to use organ meats, skins, mechanically separated meats, etc. to augment their meat supply in order to produce affordable products (Ukabam 1998).

In processed meat production connective tissue and collagen from a variety of sources (i.e. bovine hide, pork skin, natural occurring connective tissue in muscle, tendons, etc.) have been utilized in low-fat meat product formulations, extended meat product formulations, and lean meat replacement formulations. The utilization of collagen in

comminuted meat systems is dependent on the formation of undesirable characteristics that may occur due to the amount in the formulation. Defects such as poor peelability, unstable batters, gel-pocket formation, and wrinkling of the outer skin have been associated with sausage products containing large quantities of collagen (Saffle and others 1964). Collagen and connective tissue play an important role in comminuted meat products by altering product yield, texture, and stability (Jones 1984).

Meat

Definition

Throughout the years, meat has been defined by a number of different authors in a variety of ways. Aberle and others (2001) define meat as "those animal tissues that are suitable for use as food." All processed and manufactured products that might be prepared from these tissues are included in this definition. Meat is considered a source of high quality proteins. The word protein comes from the Greek word *proteios*, meaning 'primary' which suggests the importance of proteins to the nutritional well-being of humans.

Muscle Tissue

Lean meat, i.e. the muscle tissue, contains on average 70-75 percent water, 19-23 percent crude protein, 3-5 percent fat, as well as minerals and saccharides in the quantity of around 1 percent each (Kijowski 2001). Meat can be divided into three distinct muscle types: skeletal muscle, smooth muscle, and cardiac muscle. Skeletal muscles constitute the bulk (35-65 percent) of the carcass weight of meat animals and are organs of the muscular system that are attached directly or indirectly to bones. Smooth muscle is the muscle that makes up the digestive tract. The heart is composed of cardiac muscle.

From an economic standpoint, skeletal muscles are the most important of the three types of muscles. These muscles facilitate movement and/or give support to the body (Romans and others 1985). The smallest independent cellular units of mature skeletal muscle are called fibers (Copenhaver and others 1978). Skeletal muscles are a very complex contractile system made up of cylindrical, multinucleated muscle fibers (cells) of varying lengths surrounded by a layer of connective tissue known as the endomysium. Bundles of these muscle fibers are enclosed in a sheath of connective tissue known as the perimysium, while the entire muscle is surrounded by a denser connective tissue sheath called the epimysium. Figure 2.1 depicts the structural complexity of meat in which the order of decreasing size of the functional parts of the muscle are as follows: muscle, muscle bundle, muscle fiber (or cell), myofibril, myofilament (Romans and others 1985).

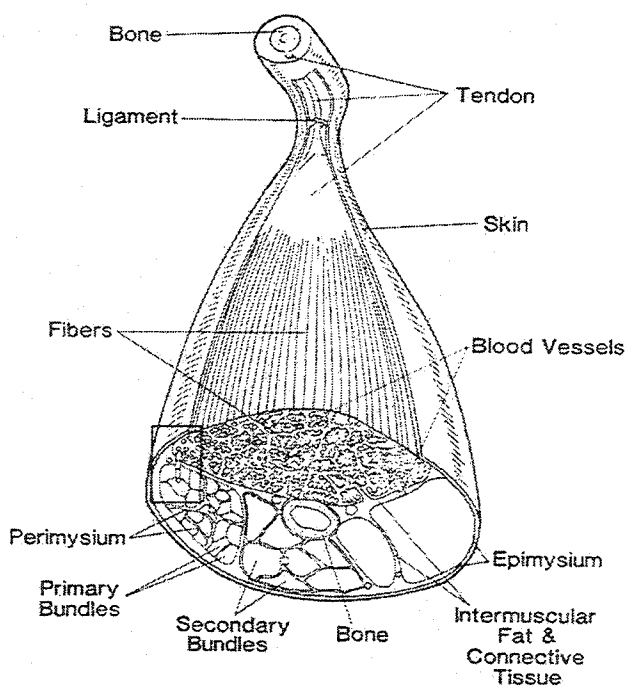


Figure 2.1. A diagrammatic representation of the structure of skeletal muscle (Reprinted from Romans and others 1985 with permission).

At the microscopic level, an enlarged portion of Figure 2.1 demonstrates a muscle fiber and associated structures (Figure 2.2). Each muscle fiber contains hundreds of myofibrils. Myofibrils are linear arrays of cylindrical sarcomeres which are surrounded on each end by a membrane system that is an elaborate extension of the muscle fiber plasma membrane or sarcolemma. These extensions of the sarcolemma, which are called transverse tubules or t-tubules, enable the sarcolemmal membrane to contact the ends of each myofibril in the muscle fiber. In between the t-tubules the sarcomere is covered with a specialized endoplasmic reticulum, called the sarcoplasmic reticulum, that contains high concentrations of calcium. The release of the calcium from the sarcoplasmic reticulum and its interaction within the sarcomeres trigger muscle contraction. Figure 2.3 displays an enlarged portion from the myofibril-myofilament region.

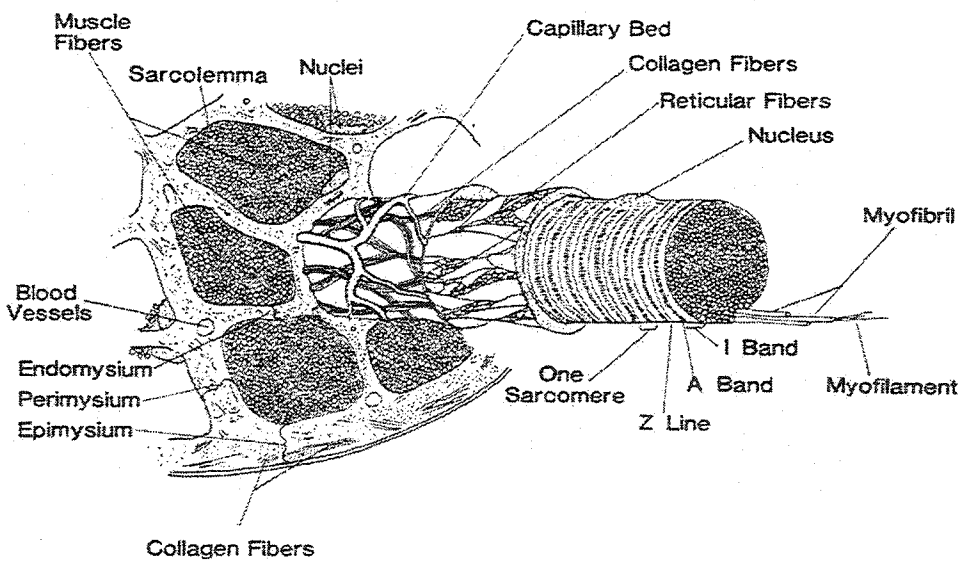


Figure 2.2. An enlarged portion of Figure 2.1 displaying a muscle fiber and associated structures (Reprinted from Romans and others 1985 with permission).

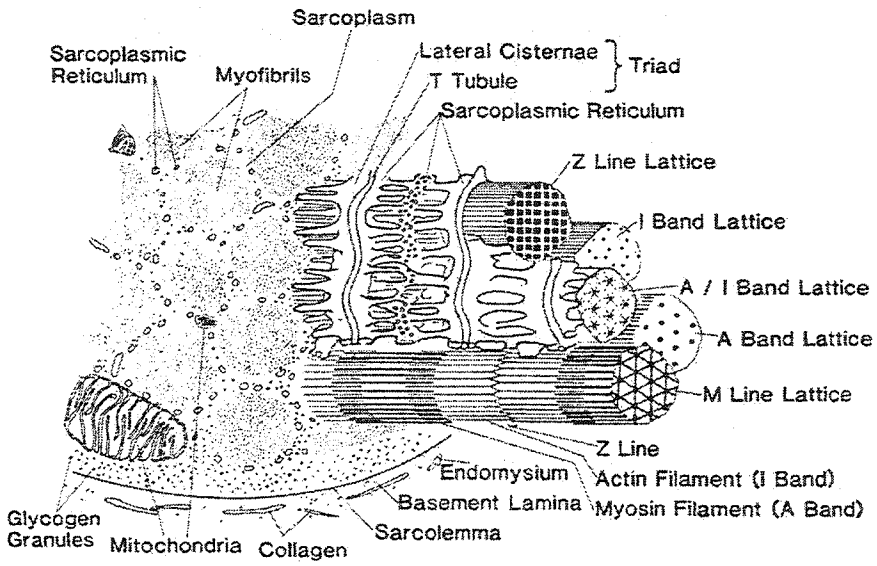


Figure 2.3. An enlarged portion from the myofibril-myofilament region showing the structures of a muscle fiber as seen with the aid of an electron microscope (Reprinted from Romans and others 1985 with permission).

With the aid of an electron microscope, skeletal muscle and cardiac muscle display alternating light and dark bands which create a striated pattern. The striation pattern is caused by the structural alignment of the myofilaments (Greaser 1991). Thick filaments (composed primarily of myosin) in the A band and thin filaments (composed primarily of actin) in the I bands create these periods of dark and light patterns. The A band denotes regions of high electron density and the I band is regions of low electron density (Garrett and Grisham 1999). A dense line bisects the I band perpendicular to the myofibril's long axis and is termed the Z line, which marks the ends of the sarcomere. Each region has a central region of slightly lower electron density called the H zone. Figure 2.4 displays the organization of skeletal muscle with the various bands and lines.

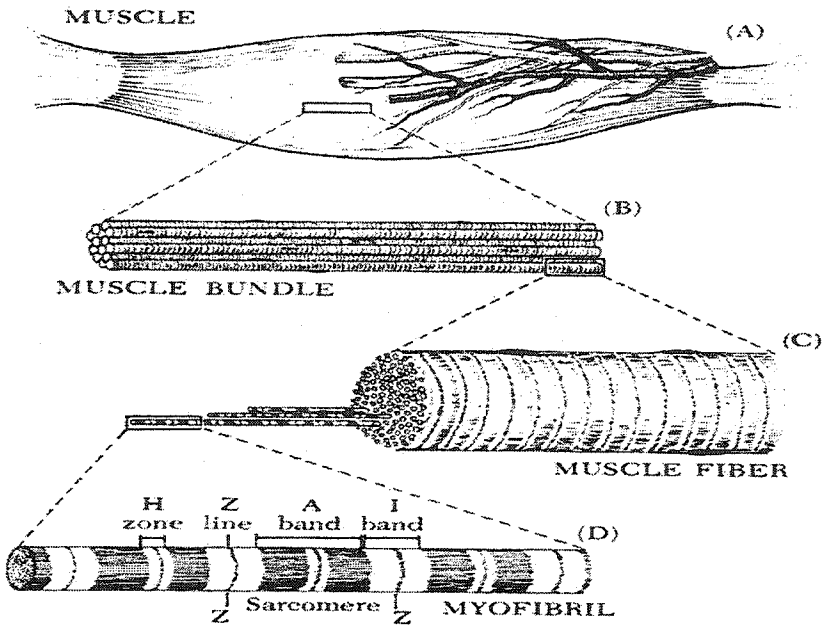


Figure 2.4. Diagram of the organization of skeletal muscle. (A) skeletal muscle, (B) a bundle of muscle fibers, (C) a muscle fiber, showing the myofibrils, (D) a myofibril, showing the sarcomere and its various bands and lines (Reprinted from Aberle and others 2001 with permission).

Muscle Proteins

Muscle proteins can be divided into categories on the basis of the location in the structure of muscle and of muscle fiber, physicochemical properties (e.g. solubility), and functionality in regard to further processing of meat. Muscle proteins form three large groups of proteins referred to as myofibrillar proteins, sarcoplasmic proteins, and connective tissue or stromal proteins. Myofibrillar proteins consist primarily of myosin, actin, tropomyosin, m-protein, alpha-actinin, beta-actinin, c-protein, troponin T, I, and C as well as other minor proteins associated with the myofibril, but which are present in very small quantities (Romans and others 1985).

Myosin and actin together account for 65 percent of the total muscle protein; tropomyosin and the troponins each contribute an additional 5 percent and the remaining 25 percent is composed of the other regulatory and structural proteins (Garrett and Grisham 1999). The other myofibrillar proteins, composed mainly of myosin and actin, are also known as "salt-soluble proteins" due to their ability to be solubilized in solutions of neutral salts of ionic strength less than 0.5 (partially soluble in ionic strength between 0.7 and 1.5) (Kolakowski 2001).

Sarcoplasmic proteins consist of myoglobin, hemoglobin, cytochrome proteins, and a wide variety of endogenous enzymes. These proteins constitute 30-35 percent of the total muscle proteins (Kijowski 2001). Sarcoplasmic proteins are soluble in solution of low salt concentration (ionic strength less than 0.1) but not in water. Since these proteins have been sometimes extracted with pure water, the name "water-soluble proteins" has become common (Kolakowski 2001). Myoglobin is presumably the most important protein of sarcoplasm because it is responsible for meat color, which is associated with product quality. Myoglobin consists of a globular protein portion (globin) and a non-protein portion called a heme ring. The heme portion of the pigment plays a special role in meat color determined by the oxidation state of the iron within the heme ring.

Stromal proteins, or connective tissue proteins, consist primarily of collagen and elastin. Collagen is the single most abundant protein found in mammalian species, being present in bone, skin, tendons, cartilage, and muscle (Romans and others 1985). Collagen, elastin, and lipoproteins of the cell membrane, including sarcoplasmic reticulum, are among the most important connective tissue proteins in the muscle (Kijowski 2001). In muscle, the connective tissue is composed mainly of the protein collagen and serves as an extracellular support for the fiber.

Connective Tissue

Overview of Connective Tissue Proteins

According to Bailey and Light (1989), there are three functions of connective tissue in the living organism: (1) to give mechanical strength to organs, (2) to provide a framework for movement and (3) to promote the right environment for cell growth and proliferation. On the other hand, the function of the connective tissue in meat does not relate to its function in the living muscle. Connective tissue plays a dominant role in giving the sensation of toughness in muscles where its content is high. Connective tissue's contribution to measurable toughness cannot be easily separated from that of the myofibrillar component, which is identified as the major contributor to initial toughness, particularly through the effects of variation in sarcomere length (Harper 1999).

Connective tissue can be divided into two major classes, skeletal connective tissue and soft connective tissue. The class of skeletal connective tissue is made up of bones, teeth, and cartilage, while the soft connective tissue makes up skin, tendons, ligaments, and blood vessels. As stated previously, connective tissues can be divided into two major proteins, elastin and collagen. Elastin will be discussed briefly, while collagen will be extensively reviewed.

Ground Substance

Ground substance is a homogeneous background material of loose connective tissue and is composed of proteins (glycoproteins), carbohydrates, lipids, and water (Cassens 1987). Ground substance is the matrix in which collagen fibers are imbedded. The major molecule of ground substance is proteoglycans which are composed of a core protein attached to various combinations of glycosaminoglycans. These proteoglycans are highly charged due to the glycosaminoglycans that contain sulfate and carboxyl groups on the

disaccharide residues. Therefore, the like charges of the proteoglycans and glycosaminoglycans cause repulsion, making these very open structures (Pearson and Young 1989). The ground substance incorporates strength and rigidity to the collagen fibers while maintaining its flexibility and elasticity.

Elastin

Elastin is a unique class of proteins with elastic properties. Elastin can be found in tissues that are subjected to continuous deformation, tension, and high pressure differentials such as skin, tendons, ligaments, muscle, and arterial walls (Bandman 1987). Elastin has a yellow appearance and is referred to as "yellow connective tissue" (Bandman 1987; Pearson and Tauber 1984). The most commonly known form of elastin is located in the *ligamentum nuchae,* or backstrap, which supports the neck of ruminant animals. The *ligamentum nuchae* is almost pure elastin (Romans and others 1985). The elastin fibers are easily stretched and when the tension is released, they recoil to return to their original length.

Ross (1971) divided elastin into two distinct groups, fibrous and amorphous components. In addition, Ross and others (1977) described that the fibrous component is first laid down, while the amorphous component was deposited secondly during muscle development. The amorphous component has a characteristic amino acid composition of 95 percent nonpolar amino acid residues with unique lysine-derived cross links (Franzblau 1971). Foster and others (1975) revealed the complete amino acid composition of elastin, while Bailey and Light (1989) stated that elastin consisted of 40 percent glycine, 10-13 percent proline, and 40 percent amino acids with hydrophobic side chains. Elastin also contains 1-2 percent hydroxyproline with similarities existing with collagen in the content of tryptophan, tyrosine, and sulfur-containing amino acids. Elastin contains two untypical

amino acids, i.e. desmosine and isodesmosine (Kijowski 2001). According to Pearson and Young (1989), the molecular weight of elastin is approximately 70,000 daltons.

Elastin is very insoluble, primarily due to its high content of non-polar amino acids and desmosine cross-links (Aberle and others 2001). Elastin is highly resistant to digestive enzymes and is not degraded by moist heat cookery methods.

Collagen

Collagen comes from the Greek word Κολλα (Eastoe 1967) or "Kolla" (Weiss and Ayad 1982), meaning glue. Collagen quantitatively predominates over the other connective tissue proteins. Collagen makes up 33 percent of the animal's total body organic matter or 60 percent of the protein (Aberle and Mills 1983). In fresh muscle tissue, collagen is present in the quantity of 1-2 percent and amounts to 6 percent weight in the strongly tendinous muscles. In chicken meat, collagen, in regard to the crude protein content, varies from approximately 2.5 percent in breast muscle to 6.5 percent in thigh muscle (Kijowski 2001).

Although connective tissue and collagen can be found in organisms throughout the animal kingdom, the exact composition can vary between species, location of the muscle within the animal, the amount of work the muscle has to do throughout life, genetic type of collagen, and animal maturity. Collagen fibrils are arranged in different ways, depending on the biological functions of the particular type of connective tissue. For example, collagen fibers are arranged in parallel bundles to yield structures of great strength but have little or no capacity to stretch in tendons. On the other hand, collagen fibrils form an interlacing network laid down in sheets in the hide of animals.

Molecular Structure of Collagen

The composition of collagen can be characterized by an unusual amino-acid composition. Collagen is a glycoprotein that contains small quantities of the sugars galactose and glucose (Hedrick and others 1994). Glycine represents nearly one-third of the total amino acid residues, while hydroxyproline comprises about 10 percent, alanine approxiamately 11 percent of the total, and proline 12 percent (Pearson and Tauber 1984). In contradiction, Aberle and others (2001) reported that hydroxyproline and proline account for one-third of collagen's total amino acid content. Tyrosine, histidine, and the sulfur-containing amino acids are present in amounts less than 1 percent (Pearson and Tauber 1984).

The structure of collagen has been widely investigated by numerous authors (Miller 1976; Glanville and Kuhn 1979; Eyre 1980). The collagen molecule is about 300 nm in length (Boedtker and Doty 1956; Schmitt and others 1955). The twelve known types of collagen share a general structural configuration in that the molecules of all collagen types are composed of three polypeptide chains, designated α-chains, in close association. These collagen α-chains contain repeating tripeptide sequences of the form Gly-X-Y along their length, where X and Y are any amino acid residues (Bandman 1987). Along the length of these α-chains, three residues are present per turn. In many cases, X is proline, while Y can be any amino acid but is often the modified amino acid hydroxyproline (Kijowski 2001; Bailey and Light 1989).

Due to the left-handed polyproline type helix of the collagen polypeptide α-chain, these chains are very unstable by themselves. When three chains wrap around each other they form a very stable right-handed triple helix characteristic of collagen called tropocollagen. A schematic of the structural organization of the collagen fiber is displayed

in Figure 2.5. The three α-chains are able to organize very tightly together due to the occurrence at every third residue of glycine, whose small side chain (a hydrogen atom) is oriented into the center of the helix (Bailey and Light 1989).

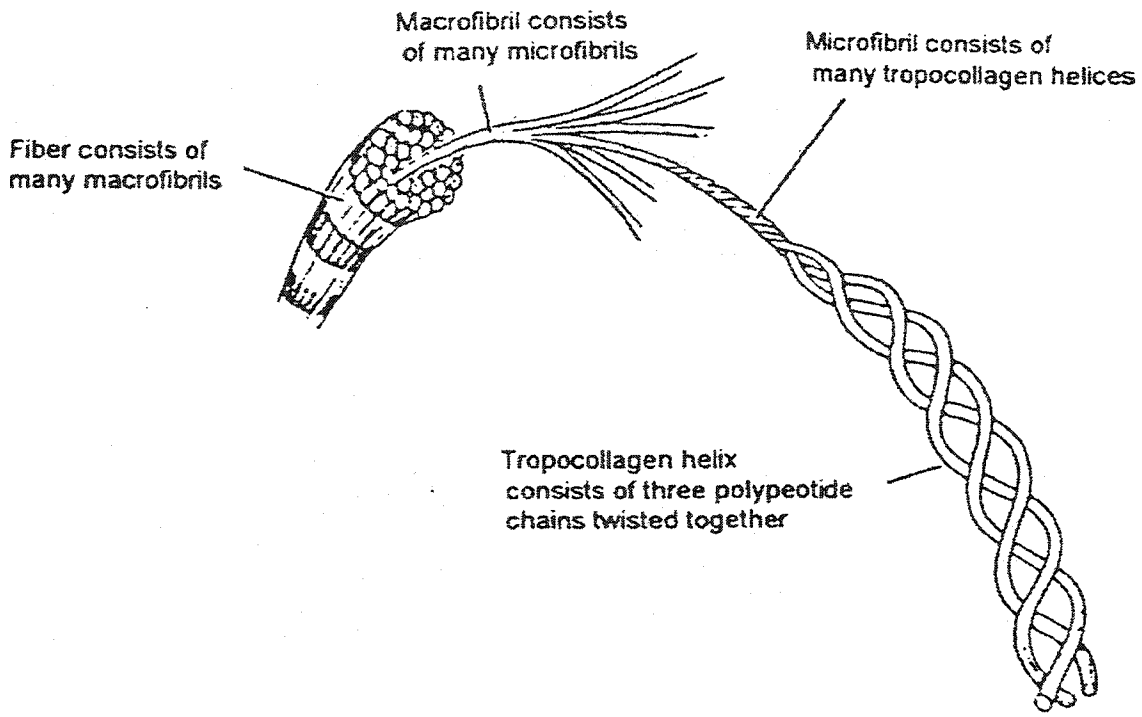


Figure 2.5 Collagen fiber structure (Reprinted from Kijowski 2001 with permission).

The tropocollagen molecule is a long cylindrical protein 2800 to 3000 Å in length and 14 to 15 Å in diameter (Jones 1984). The right handed superhelix has a molecular weight of about 100,000 daltons. The tropocollagen molecules are linked end to end and adjacent to each other in a quarter staggered fashion to make up a collagen fibril which creates a banding pattern when viewed under an electron microscope. Figure 2.6 displays a summary of the collagen structure configuration.

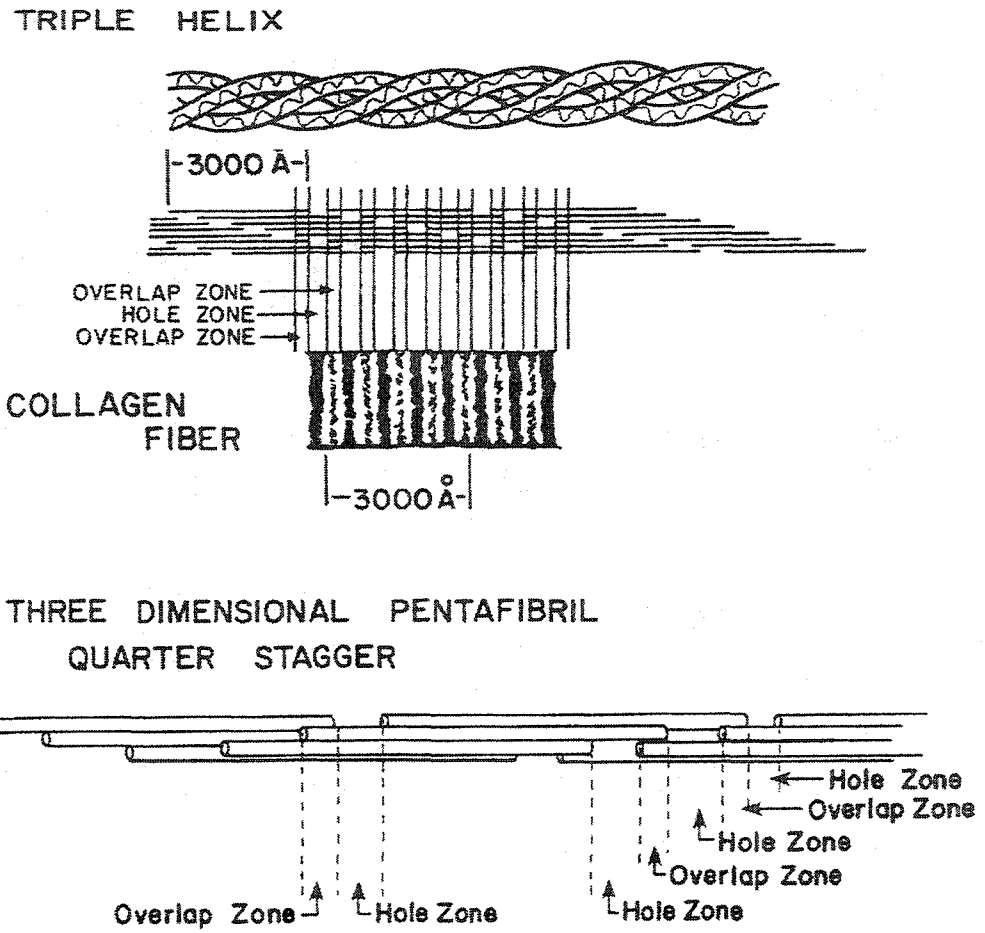


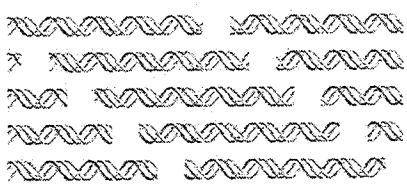
Figure 2.6. Collagen structure configuration (Reprinted from Dutson 1976 with permission).

Collagen Classification

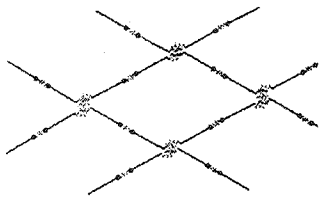
Most collagens have been characterized biochemically, and it has been found that each kind of tissue contains a characteristic composition of collagen types. The types of collagen in muscle and their chemical structure have been described in detail by many authors (Aberle and Mills 1983; Bailey 1984, 1987, 1989; Jones 1984; Pearson and others 1987). Based on their macromolelcular structures, collagens can be divided into three groups: striated fibrous collagen (Types I, II, and III); basement membrane type or non-fibrous collagen (Type IV); and microfibrillar or filamentous collagen (Types VI and VII)

(Pearson and Young 1989; Bailey and Light 1989). Schematics of the various types of collagen are found in Figure 2.7 and Table 2.1 summarizes all discussed collagens.

Fibrous Collagens
Types I, II, III, V, XI



Non-Fibrous Collagens
Type IV



Filamentous Collagens
Type VI, VII

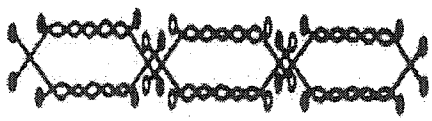


Figure 2.7. Schematic diagram of collagen types (Reprinted from Bailey 1989 with permission).

Table 2.1. Classification, type, tissue location, and molecular composition of collagen.

Classification	Type	Tissue Location	Molecular Composition
Striated Fibrous Collagen	I	Tendons, skin, bone, and all intra-organ connective tissues	$[\alpha1(I)]_2$ chains $[\alpha2(I)]_1$ chain
	II	Cartilage, intervertebral disc	$[\alpha1(II)]_3$ chains
	III	Skin, embryonic tissue, scar tissue, arteries, heart value, and many intra-organ connective tissues	$[\alpha1(III)]_3$ chains
	V	Tissue of basement membranes	$[\alpha1(V)]_1$ chain $[\alpha2(V)]_1$ chain $[\alpha3(V)]_1$ chain
Non-Fibrous Collagen	IV	Non-fibrous sheaths underlying epithelial cells, muscles and nerves	$[\alpha1(IV)]_2$ chains $[\alpha2(IV) + \alpha3(IV)]_1$ chain
Filamentous Collagen	VI	Vascular system, cartilage, and cornea	$[\alpha1(VI)]_1$ chain $[\alpha2(VI)]_1$ chain $[\alpha3(VI)]_1$ chain
	VII	Placental dermal basement membrane	Unknown

Striated Fibrous Collagen

Types I, II, III collagen and the minor collagens V and XI occur predominantly in fibrous form in the extracellular matrix (Bandman 1987). The most prevelant type, designated Type I, is found as the main collagenous component of tendons, skin, bone, dentine, and all intra-organ connective tissues. According to Bailey and Light (1989), each molecule is a polymer (heteropolymer) of two α1 chains (called α1(I)-chains) and one α2 chain (called the α2(I)-chain). The α1(I)- and α2(I)-chains are products of different genes

located on different chromosomes. Type I produces fibers of high tensile strength due to the comprehensive network of intermolecular cross-links laid down within the matrix during muscle development.

Type II collagen is the major component of cartilage and is a homopolymer of three identical chains called α1(II)-chains. Although Type II collagen shows about 75 percent amino acid sequence homology with Type I (Bailey and Light 1989), Type II collagen has a hydroxylysine content which is three times greater than the content found in Type I collagen. Type II collagen is much finer than Type I which has been linked to the higher carbohydrate content in Type II.

Type III collagen also consists of three identical chains which are defined as α1(III)-chains. Unlike Types I and II collagens, Type III contains a cysteine residue located at the C-terminal end of the triple helix (Bailey and Light 1989) which contributes to the low solubility of this collagen (Dutson 1976). Type III collagen is found in skin, embryonic tissue, scar tissue, arteries, heart value, and many intra-organ connective tissues.

Although Type V collagen is a minor collagen, it can be isolated from tissues rich in basement membranes (Bailey and Light 1989). Bailey (1987) grouped Type V collagen as a pericellular (cell-associated) collagen. Type V collagen has a high hydroxyproline and hydroxylysine content, like Type IV collagen (discussed in the next section). Moreover, Type V also contains 3-hydroxyproline but does not have cysteine. Type V collagen exists as a heteropolymer of two chains, defined as α1(V) and α2(V), with the ratio of the two chains 2:1 respectively (Bailey and Light 1989). A third chain also exists, denoted α3(V), which forms a trimeric molecule or a dimeric co-polymer with either of the α1(V) chain or α2(V) chain.

Non-Fibrous Collagen

Type IV collagen does not form typical collagen fibrils but fine networks in the basement membranes surrounding muscle cells (Sanes and Cheney 1982). More specifically, Type IV collagen can be found in nonfibrous sheaths underlying epithelial cells, muscles, and nerves. Type IV collagen molecules self-assemble to form a "chicken wire" network structure which acts as the basic framework for all basement membranes (Bailey 1989). Type IV collagen consists of two α1(IV) chains and a hybrid chain consisting of α2(IV) + α3(IV) polypeptides. Type IV collagen has a length of approximately 400 nm.

Filamentous Collagen

Type VI and VII are grouped in the filamentous collagens which possess variable molecular lengths and form a variety of filamentous structures. Type IX and X collagen are also grouped as filamentous collagen. Type VI collagen is widely distributed in the extracellular matrix, e.g. the vascular system, cartilage and cornea. Type VI collagen exhibits a molecular composition of three chains, α1(VI), α2(VI), and α3(VI), which arrange themselves in an antiparrallel alignment. Type VI monomers extracted from aortic intima revealed a rod-like helical section 105 nm long with a large globular domain on each end (Bailey and Light 1989). Bailey (1987) also isolated Type VI collagen with a length of 115 nm from aorta.

According to Bailey (1989), Type VII microfibers make up the placental and dermal basement membrane and act as an anchor between the basement membrane and underlying matrix. Although the exact molecular composition of the collagen chains is unknown, Type VII collagen has been isolated in dermal basement membranes and has a length of 450 nm, 1.5 times longer than fibrous collagens.

Collagen Cross Linking

Cross linking of amino acids is vital for the strength and function of collagen fibrils. Collagen attains its high structural stability and resistance to mechanical and chemical attack by the formation of two types of cross linking, intra- and intermolecular cross links (McClain 1976). Intramolecular cross links are said to be those which form between α-chains within the same molecule. Intermolecular cross-links are those which form between α-chains in different molecules.

The precursors for collagen cross linking are formed through the oxidative-deamination of specific lysine residues in the terminal non-helical region of the collagen molecule (Bailey 1989). During the maturation of the animal, two types of cross links occur, reducible and non-reducible (stable) cross links. The aldol condensation product of two activated aldehydes is often referred to as a reducible cross link because it can be broken by mild reducing conditions, unlike mature (non-reducible) cross links which are stable to high temperature and extreme of pH (Bandman 1987). In young developing animals, the occurrence of reducible cross linking is at a rapid rate. Alternatively, as the animal matures, reducible cross links are converted to stable, non-reducible cross links (Bailey and Light 1989).

The effect and proportion of this transformation (reducible vs. non-reducible cross links) greatly determine meat tenderness. Non-reducible (insoluble) cross links reduce collagen solubility, raise conformational transition temperature, and increase meat toughness (Whiting 1989). McCormick (1989) noted specie, age, dietary, and husbandry as possible factors that affect the quantity and extent of collagen cross linking.

Thermal Stability and Denaturation of Collagen

Denaturation can be defined as a change in the conformation of the native structure of a protein without an alteration in the primary amino acid sequence (Jones 1984).

Denaturation temperature is the temperature at which unfolding takes place. This unfolding is believed to involve two steps: (1) the separation of the triple helices into individual ones and (2) the unfolding of the individual helices into random coils (Bernal and Stanley 1987). The separation of the triple helices involves the disruption of water bridges (hydrogen-bound) between the helices of the tropocollagen molecule, while the unfolding of the individual helices involves the disruption of intrahelical hydrogen bonds (Purslow 1985).

The thermal stability of molecular collagen correlates closely with the hydroxyproline content of vertebrate collagens (Aberle and Mills 1983). The heating of collagen has a major impact on the textural characteristics of meat and meat products. Many things may affect the transformation of collagen such as the rate of temperature increase, duration of heating, moisture content, and the highest temperature achieved.

Changes in collagen proteins during cooking are summarized by Bailey (1984) and Gillet (1987ab). At 40 °C, connective tissue has maximum toughness and at 60 °C, collagen shrinks. At 75 to 80 °C the collagen melts, eventually losing all structure and strength (gelatinization). Gelatin is the random mixture of monomers, dimers, and trimers (free chains α, β, and γ) of the collagen helical peptide chains which have become unraveled. The rate of gelatinization increases with temperature, occurring very rapidly at 125 °C. The denaturation temperature of collagen from spent hen epimysium, tendon, and skin were 69.9, 72 and 69.4 °C, respectively (Kijowski 1993).

Heat denaturation is the most widely used and most important means of altering the detrimental properties that collagen contributes to meat systems. Heating collagen in water leads to its transformation into a colloidal solution of high viscosity and gelation properties. At temperature above the thermal shrinkage (T_s), collagen is converted to gelatin with time and moisture influencing the conversion rate. Conversion to gelatin does not readily occur

except under prolonged moist heat conditions (Jones 1984). Cooling the gelatin regenerates the triple helix conformation for short stretches via random recombination of the polypeptide chains, but they are not in proper axial register (Creighton 1993).

Jones (1984) and Bailey and Light (1989) described that as collagen fibrils are heated, a collapse of the structure and subsequent shrinkage occurs to the fiber. Collagen fibrils are known to shorten up to 33 percent of their original length (Aberle and others 2001). In a study of bovine intramuscular collagen by Judge and Aberle (1982), it was determined that the temperature at which this transition occurs is dependent on the physiological maturity of the animal, time postmortem, and the ionic environment of the muscle tissue.

Connective tissue proteins are neither soluble in neutral salt solutions of ionic strength less than 0.5, nor in weak (0.05 N) solutions of NaOH and HCl (Kolakowski 2001). Collagen partially dissolves in the solution of neutral salts as well as in acidic and basic solutions. Acid extracted soluble collagen can be obtained by using acetic or citric acid solution. Piez (1967) determined that the largest proportion of soluble collagen can be obtained when the collagen is extracted at a pH of approximately 1.5 because the amount of extractable collagen increases as pH decreases.

Kijowski (1993) examined the effect of three marination solutions (2 percent salt, 1.5 percent lactic or 1.5 percent acetic acid) on spent hen drumstick connective tissues (epimysium, tendon, and skin) to determine the thermal transition (denaturation) temperatures. Untreated epimysium, tendon, and skin exhibited denaturation temperatures of 69.9, 72.0 and 69.4 °C, respectively. Thermal denaturation temperatures were reduced by 20 to 25 °C with weak acid marinations compared to marination with salt (3-4 °C).

Hill (1966) outlined a procedure to determine the existing level of soluble collagen and collagen further solubilized by heating in fresh beef. It involved heating a dried homogenized muscle sample with 25 percent Ringer's solution in a 77 °C water bath for 63 minutes. Due to the fact that this method involved heating the processed products to higher temperatures than the products would normally receive, a greater solubilization would have occurred. Eilert and Mandigo (1993) conducted a study to modify existing procedures to separate soluble collagen from thermally processed meat samples without solubilizing more collagen. It was determined that in a 48-52 °C water bath, 10-15 minutes was sufficient to separate soluble collagen from thermally processed meat products by solubilizing more collagen.

Skin

Skin varies between animal species and within any one species it varies with age, sex, and region of the body. As noted previously, the biochemical functions of the various connective tissues are both varied and specialized. Skin needs to tear and be shear resistant as well as being waterproof, while having a degree of elasticity (Bailey and Light 1989). This elasticity of skin collagen is from the fibers that form large fiber bundles which vary in size depending on their depth below the skin surface. These large fiber bindles are randomly oriented to form a flexible but mechanically stable matrix.

According to Naghski and Feairheller (1987), skin is composed of three major layers: the surface or pigmented epidermis; the underlying connective tissue of corium; and the subcutis. The epidermis covers the entire skin, and also extends downward from the surface as a tubular invagination and forms a part of the hair follicle. The upper section of the corium layer is composed of many elastin fibers interwoven with fine reticulin and collagenous fibers. The lower portion of the corium layer consists predominantly of large

bundles of collagen fibers interwoven in multiple directions. The subcutis, which provides attachment to the underlying organs, consists of loose networks of collagen and elastin fibers.

Hides, pelts, and skins are used for a variety of purposes from leather apparel and garments for the general public to collagen casings and meat by-products for the meat industry. In 1987, Naghski and Feairheller reported that the pork industry was slowly undergoing a change to skinning hogs which allowed the marketing of whole pigskins. The utilization of these pigskins as a raw material for processed meat has been extensively researched, while skins from other species have been studied by a few authors.

Utilization of Collagen in Processed Meat Products

Collagen is present in comminuted meats and meat products either as a natural component of the connective tissue of the meat used in the process or as an additive. Saffle and others (1964) reported undesirable characteristics such as poor peelability, unstable batters (meat emulsions), gel pocket formation, and wrinkling of the outer skin that have been associated with sausage products containing large quantities of high collagen meats. Wiley and others (1979), as well as Carpenter and others (1979), compiled an extensive review of 21 different sausage meats to determine total collagen, insoluble collagen, and percentage of soluble collagen present in each meat. Furthermore, Porteous (1981) presented collagen data for 15 beef, 41 hog, and 25 sow cuts and trimmings to be used for least-cost, constant quality, computer formulations of sausage products.

Collagen may be added for specific binding/structural reasons such as the addition of graded collagen as a binding agent or as a filler. Filler collagens are added to processed products to greatly reduce the cost of producing a particular meat product. These filler collagens exhibit inferior properties of binding compared with higher quality collagen

additives and naturally occurring meat collagen. Gillet (1987c) reported the use of high collagen items extensively in processed products can be very detrimental to product cooking stability and texture. Collagen and connective tissue play an important role in comminuted meat products by altering product yield, texture, and stability (Jones 1984).

Jobling (1984) explained that collagenous material used in the manufacture of meat products can come from pork rinds, hide sections, natural and reconstructed casings, gristle, edible greases (from rendered body fats), and edible bone collagens. High collagen meat sources including pork skins, head trimmings, or gelatin were used to improve the bind of jellied products such as headcheese, souse, and scrapple (Ockerman and Hansen 1988). Bailey and Light (1988) listed hide collagen, bone collagen, offal collagen, and skeletal muscle collagen as sources of collagen to be used in sausage manufacturing.

Collagenous material from mammals, especially after conversion into gelatin, has been widely studied; many industrial applications have also been reported. Henrickson (1980) reported that beef hide protein, collagen, is a useful extender, moisturizer, texturizer, or emulsifier in different food systems. Non-detrimental effects to coarse-ground sausages were observed by Bailey and Light (1988) with levels up to 30 percent of collagen from the corium layer of hides. Wiley and others (1979) suggested that as a "rule of thumb," use of high collagen meats should be limited to 15 percent of the meat block. A recommendation by Rust (1987) stated that collagen should be limited to 25 percent of the total protein content in a sausage, while Müller and Wagner (1985) concluded that an addition of rind and sinew should be limited to 5 percent of frankfurters to prevent undesirable sensory characteristics.

The majority of research conducted using connective tissue/collagen has been performed in finely comminuted meat systems. The sources of connective tissue/collagen

used in research are quite numerous: beef tripe (Randall and others 1976; Jones and others 1982); tendon from beef hind leg muscles (Sadler and Young 1993); desinewed cow meat (Ladwig and others 1989); desinewed shank muscles from beef carcasses (Eilert and Mandigo 1993; Eilert and others 1996ab; Calhoun and others 1996ab; Osburn and others 1999); desinewed connective tissues from pork (Delmore and Mandigo 1994); beef skin (Satterlee and others 1973; Asghar and Henrickson 1982; Rao and Henrickson 1983, Chavez and others 1985); pork skin (Satterlee and others 1973; Sadowska and others 1980; Puolanne and Ruusunen 1981; Quint and others 1987; Delmore and Mandigo 1994; Fojtik 1997; Osburn and others 1997; Prabhu and Doerscher, 2000); poultry skin (Osburn and Mandigo 1998; Prabhu 2003); turkey skin (Acton and Dick 1978; Prabhu 2003); and meats containing high amounts of connective tissue (Maurer and Baker 1966; Carpenter and others 1979; Ambrosiadis and Wirth 1984).

Beef Tripe

Randall and others (1976) replaced the beef component in a meat emulsion system up to 80 percent with frozen honeycomb beef tripe. The authors noted minimal changes in cooked yields at the 20 percent replacement level, but at 40 percent, the tripe caused adverse yield results. Drip losses paralleled the cooked yield results and at the 60 and 80 percent replacement levels, measurable lipid losses occurred with the tripe. Due to the nature of tripe (connective tissue protein), reduced-fat and water binding occurred by replacing the salt-soluble muscle protein. Firmness decreased at the 60 and 80 percent replacement levels and cohesiveness decreased at all replacement levels.

Jones and others (1982) conducted research in which beef tripe was used in 30 batches of bologna as a collagen source. Meat emulsions were prepared with five tripe levels (0, 10, 20, 30 and 40 percent of the formulation). Total collagen and insoluble

collagen were significantly higher ($P<0.05$) for each increasing tripe level. Only minor differences were observed in the soluble collagen fractions. In comparison to lower tripe levels, the 40 percent tripe level had a lower smokehouse yield ($P<0.05$). The authors also concluded that the higher the collagen content in the formulation leads to a more "brittle" emulsion which was determined by lower hardness and chewiness scores. Furthermore, the authors reported decreased firmness and bind values in the cooked product and decreased visoelastic properties in the raw batter in formulations that contained tripe levels greater than 10 percent.

Tendons from Beef Hind Leg Muscles

Sadler and Young (1993) replaced a portion of the lean in a conventional emulsion formulation with tendon from beef hind leg muscles. The tendons were homogenized and used either in a raw state or a preheated state. In the preheated treatment, the homogenized tendon was subjected to four temperature ranges (50, 60 70, 80 °C). In the first study, all treatments were observed by replacing 20 percent of the meat protein with 20 percent tendons (all treatments). Hardness doubled by replacement with raw tendon or tendon heated at 50 °C, but returned to approximately no-replacement levels at temperatures higher than 50 °C.

In the second study by Sadler and Young (1993), a portion of the lean meat was replaced with 0, 5, 10, 15, 20 or 25 percent tendon homogenate (raw and preheated at 70 °C). All attributes measured by the sensory evaluation decreased with increasing collagen content, but to a lesser extent with preheated tendon. By a comparison of panel scores and texture profile analysis, it was determined that reduced fracturability was the texture parameter that panelists objected to when heated tendon replaced some of the lean. The

authors concluded that a 60 °C preheated tendon homogenate at a 20 percent lean meat replacement can be effective for positive sensory attributes.

Desinewed Connective Tissue

Desinewed connective tissue has been obtained from cow meat and beef hind shank meat and utilized by many authors. Ladwig and others (1989) added two levels of collagen to meat emulsions to determine the effect of muscle collagen on emulsion stability. The authors revealed that adding additional collagen to meat emulsions shortened the total chopping time and decreased emulsion stability, but had no effect on protein solubility.

Eilert and Mandigo (1993), Eilert and others (1996ab), and Calhoun and others (1996ab) performed extensive research with desinewed connective tissue from beef hind shank meat. Eilert and Mandigo (1993) noted that thermal processing yield losses declined with increased modified connective tissue level (0, 10, 20, 30, 40 percent) and hypothesized that the addition of modified connective tissue may be effective for reducing processing yield losses in low-fat meat systems. Eilert and others (1996ab) and Calhoun and others (1996ab) studied the relationship between phosphates and desinewed beef connective tissue. Collagen solubility was maximized with a 3.5 percent acidic phosphate solution, while hydration was optimized with a 3.5 percent alkaline phosphate solution (Eilert and others 1996a). The authors concluded that exposing connective tissue to high concentrations of phosphate will dramatically alter binding and solubility.

Calhoun and others (1996ab) expanded on the previous research with studies of preblending connective tissue with phosphates. While Calhoun and others (1996a) revealed that preblending sodium acid pyrophosphate with modified beef connective tissue and subsequent addition of alkaline phosphate created a modified connective tissue product

similar to the control product, Calhoun and others (1996b) determined that preblending modified connective tissue and sodium tripolyphosphate was not beneficial.

Osburn and other (1999) determined that the incorporation of desinewed beef connective tissue gels in reduced-fat bologna decreased ($P<0.05$) product hardness and increased juiciness, which indicated potential for the utilization of beef connective tissue gels as water-binders and texture-modifiying agents in reduced-fat comminuted meat products.

Beef Hide (Skin)

Although hamburger is not considered a processed product, hamburger is an intermediate particle-size product (Whiting 1989) and defined in the Code of Federal Regulations with section 319.15b (USDA 2002a) as: "Chopped fresh and/or frozen beef, with or without added beef fat and /or seasonings. Shall not contain more than 30 percent fat, and shall not contain added water, binders or extenders. Beef cheek meat may be used up to 25 percent of the meat formulation." Chavez and others (1985) added bovine hide collagen as an extender to ground beef replacing lean meat at a level of 0, 10, or 20 percent. Beef patties with the collagen were found to be superior ($P<0.05$) in juiciness by the taste panel, while the flavor, texture, and overall acceptability decreased as the collagen level increased.

Asghar and Henrickson (1982) investigated the effect of the addition of food-grade bovine collagen at 10, 20, and 30 percent levels on other protein fractions in bologna. The authors revealed that the solubility of sarcoplasmic and myofibrillar proteins decreased, while percent solubility of collagen increased with increasing level of added hide collagen. Rao and Henrickson (1983) replaced 20 percent of the lean meat component in bologna with 20 percent beef hide collagen. The replacement did not alter the functional characters

such as raw bologna emulsion stability and pH, cook yield, pH, water activity, and expressible moisture in the cooked bologna. The bologna with collagen had increased ($P<0.05$) shear force values compared to bologna with no collagen.

Pork Skin

Satterlee and others (1973) produced pork skin hydrolyzates and replaced non-fat dry milk in a sausage formulation. The utilization of pork skin hydrolzates produced sausage with a slightly better water and fat holding ability even though the emulsion capacity was slightly lower than the capacity of non-fat dry milk emulsions.

Sadowska and others (1980) and Sadowska (1987) utilized varying levels (5, 15, 20, or 25 percent) of raw and cooked (100 °C for 0-90 minutes) pork skin collagen to examine the rheological properties of sausage batters and cooked sausage, respectively. It was reported that replacing 20 percent of the meat protein with pork skin collagen decreased batter viscosity and cooked sausage elasticity. Incorporation of cooked skin (15 percent of the total protein) resulted in batter with higher viscosity and higher cooked sausage elasticity when compared to batter or cooked sausage not containing pork skin collagen. The authors concluded that the addition of greater than 2.5 percent pork skin collagen would result in altered cooked sausage texture and appearance. Puolanne and Ruusunen (1981) hypothesized that connective tissue may be important for the water binding capacity and firmness of cold sausage.

Quint and others (1987) produced a loaf product that contained flaked pork skin and water that was pre-emulsified by passing it through an emulsion mill. The authors determined that the incorporation of the pre-emulsion improved bind of the emulsion and increased firmness, redness (a value), and yellowness (b value) colors of the loaf product. Delmore and Mandigo (1994) also used flaked pork skin sinew to low-fat, high-water added

frankfurters at varying levels (0, 10, 20 percent of the formulation). Cooking yield, texture, and purge of the frankfurters were not altered by replacement levels of up to 20 percent pork connective tissue. There was no difference in juiciness, flavor, texture, or overall acceptability detected by consumer sensory panelists between frankfurters containing 0 to 10 percent pork sinew. Fojtik (1997) incorporated flaked pork skin at levels of 10 and 20 percent into fresh pork sausage. The author reported that consumer panelists ranked low-fat sausage patties containing 10 percent pork skin higher for flavor, juiciness and overall acceptability than patties containing higher fat levels or pork skin levels. Fojtik concluded that the patties that contained 10 percent pork skin were more tender than those containing 20 percent pork skin (Fojtik 1997).

Osburn and others (1997) produced gels from flaked pork skin with varied amounts of added water (100, 200, 300, 400, 500, 600 percent). These pork skin gels were utilized in reduced-fat bologna at levels of 10-30 percent addition. The greatest purge for any bologna occurred with the 600 percent added water, 30 percent addition treatment. Taste panel analysis revealed that juiciness scores increased as added water and percent gel addition increased. The overall acceptability of the pork connective tissue bologna tended to increase as added gel and added water increased. The authors summarized that the incorporation of pork connective tissue gels varied the functional, textural, and sensory attributes in reduced-fat bologna (Osburn and others 1997).

More recently, Prabhu and Doerscher (2000) utilized processed pork skin collagen in reduced-fat frankfurters to increase cooking yield and decrease purge in the final product. The authors also researched the effect of pork collagen in fat-free pork sausage formulations. The results indicated increased cooked yields with a reduction in cooked diameter shrink. The authors concluded that the addition of 1 percent hydrated collagen at

a 1:4 ratio is a cost-effective (e.g improved yields), functional ingredient that can improve the quality (e.g. texture improvement) of various meat products.

Hoogenkamp (2001) cited the use of pork skin (rinds) in the production of pre-emulsions, which are another method to incorporate this raw material into emulsified meats. Pork skins are pre-blanched for about 20 minutes at 80 °C to soften the collagen tissue. The pork skins are added into the chopper prior to the addition of fat and chopped to a fine particle size which allows an increase in the pre-emulsion ratio utilized in the formulation.

The skins come from carcasses that have been previously inspected by the USDA. As the raw material (skin) enters the processing facility, it is further inspected by USDA inspectors. Pork skins are then processed to yield processed pork skin collagen, also referred to as functional meat proteins, which are available in chunk, granular, and powder forms. The production of pork skin collagen is shown in Figure 2.8.

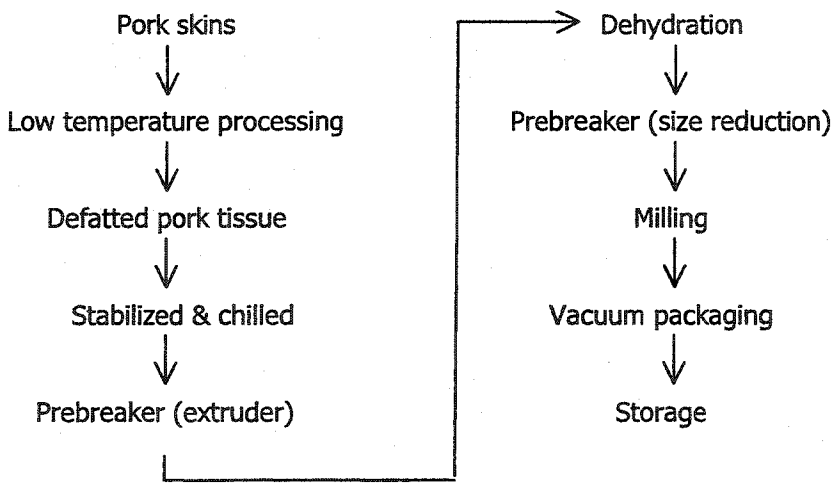


Figure 2.8. Schematic of the production of pork collagen (Provided by Proliant Inc.).

Poultry / Turkey Skin

Poultry skin is also a source of collagen that may be used in comminuted meat systems. Campbell and Kenney (1994) listed poultry skin as generally being a filler ingredient in poultry or mixed-species batter sausages. The authors described that poultry skin may be listed on ingredient labels as "poultry by-products" and in other products skin cannot be added in higher proportion than occurs naturally.

Due to its high collagen content, broiler skin meat possessed inferior emulsifying capacity (Maurer and Baker 1966). Moreover, Hudspeth and May (1969) analyzed skin, heart, and gizzard tissues of turkeys, hens, broilers, and ducklings for emulsifying capacity of salt-soluble protein. The authors reported that skin was the least desirable tissue in emulsification properties and was not as effective in emulsifying ability as muscle tissue from the same class of poultry.

On the other hand, Prabhu (2003) reported that functional collagen proteins from chicken and turkey skins can bind three to four times their weight in water and can form a firm elastic "cold" gel producing texture characteristics that are similar to meat. Prabhu stated that this gel functions as a matrix stabilizer of finely comminuted and coarse-ground meat products such as frankfurters or sausages. The author suggested that collagens immobilize free water and prevent moisture loss during heat processing as well as improve texture while reducing purge loss.

Commercial production of chicken and turkey collagen has been accomplished. A general schematic of the production of chicken and turkey collagen is displayed in Figure 2.9. Poultry collagens were approved as a flavoring in standard and non-standard processed meat and poultry products by the USDA's Food Safety and Inspection Service

(FSIS) in March of 2001. The collagens were approved to be used at a level sufficient for purpose.

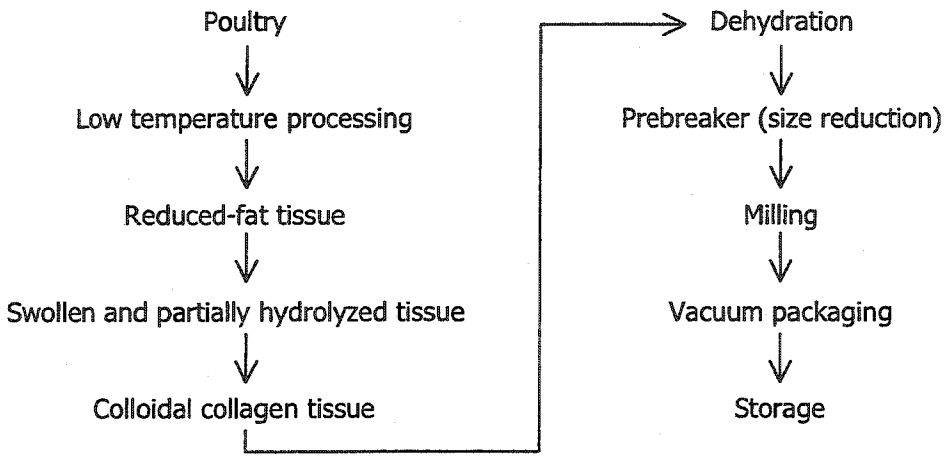


Figure 2.9. Schematic of the production of chicken and turkey collagen (Provided by Proliant Inc.).

Poultry collagens have been researched in numerous processed meat products such as chicken nuggets, breakfast sausage, coarse-ground smoked sausages, and fresh ground meat products (i.e. turkey burger). Prabhu (2003) controlled purge and texture of turkey smoked sausages when 5 percent of the turkey thigh meat was replaced with 1 percent turkey collagen and 4 percent water. Furthermore, a cost savings of 3.1 percent was recognized. It was also reported that poultry collagens could be incorporated by either tumbling or massaging the collagen into whole muscle meat products such as chicken breast and chicken wings.

The result of adding 1 percent to 2 percent poultry collagen to replace a portion of the lean meat block may effect processing characteristics such as water holding capacity which in turn effects finished product yields as well as texture characteristics. A substantial

cost savings could be achieved without a reduction in eating quality characteristics of the final processed meat product.

Meat Emulsions and Batters

True Emulsion

A true emulsion is defined as a heterogeneous mixture of two immiscible liquids, one of which is dispersed in the form of small droplets or globules in the other liquid. The liquid that forms the small droplets is called the dispersed-phase, whereas the liquid in which the droplets are dispersed is called the continuous phase. Examples of true emulsions are mayonnaise, homogenized milk, or vinegar and oil salad dressings that do not separate.

Emulsions are generally unstable unless emulsifying or stabilizing agents are present. Emulsifying agents have a distinguishing characteristic of having affinity for both water and fat. The hydrophilic (water-loving) portions have affinity for water, while the hydrophobic (water-hating) portions have affinity for fat. When the hydrophobic and hydrophilic portions can align themselves between both the lipid and aqueous phase, the affinities are best satisfied. As the proteins unfold, the hydrophobic portions of the protein will orientate itself toward the lipid (fat) phase and the hydrophilic portions will orientate themselves toward the continuous phase (Romans and others 1985).

Meat Emulsion (Batter) and Emulsion Formation

Meat emulsions (batters), which are not true emulsions since the two phases involved are not liquids, can be defined as follows: "A meat emulsion is a finely comminuted dispersion of lean and fat particles into a two-phase system which consists of a dispersed phase (fat droplets) and a complex continuous phase composed of water,

solubilized proteins, cellular components and miscellaneous spices and seasonings (Romans and others 1985)."

The formation of a typical meat batter consists of two related transformations: (1) swelling of proteins and formation of a viscous matrix which ultimately forms a heat-set gel upon cooking, and (2) emulsification of dispersed fat droplets by solubilized proteins (Aberle and others 2001). The subcellular-sized fat particles are suspended by a protein coating. The fat is effectively suspended by the protein coating due to the hydrophilic groups of the protein which attach themselves to water and lipophilic groups which attach themselves to the fat (Rust 1987). To understand meat batters more thoroughly, the components of a meat batter must be known. Figure 2.10 diagramatically displays the components of meat batters.

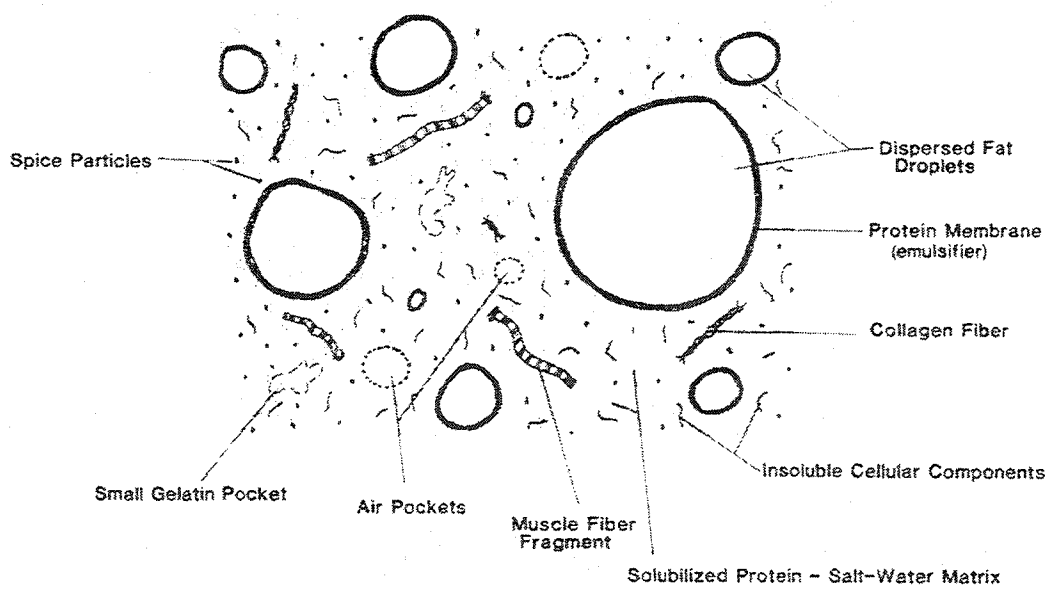


Figure 2.10. The components of a meat batter (Reprinted from Romans and others 1985 with permission).

Meat emulsions are made by grinding or chopping meat and water with the addition of sodium chloride to a fine homogenate, forming the matrix in which animal fat (mostly pork fat) is dispersed (Schut 1976). The addition of ingredients plays an important role in the formation and stability of a meat emulsion. A typical procedure begins with the addition of lean meats into the chopper. These lean meats contain the highest amounts of myofibrillar proteins. In successful meat emulsions, the salt-soluble myofibrillar proteins, especially myosin or the actomyosin complex, are generally considered to be the principle emulsifiers. Since these myofibrillar proteins are salt-soluble, for the most effective reaction, the salt level should be 4 to 4.5 percent of the lean meat (Rust 1987).

Since the swelling and protein extraction is more effective at low temperatures, initial chopping should be performed keeping the temperature of the pre-emulsion at 3 °C (37 °F). As the lean meats are chopped with the salt, the myofibrillar proteins are extracted. The solubilized (extracted) myosin gives a tacky adhesive body to chopped meat batters. Although lean muscle contains approximately 75 percent water, additional amounts are usually added to the myosin extraction. Part (approximately half) of the ice or water is added to the extracted myosin. The water is both entrapped in the open myofibrillar structure as well as bound to the negative charges of the protein. Water is the preferential solvent of myosin in the presence of salt which enables the meat to hold considerably more water (Gillet 1987c).

The addition of salt and alkaline phosphates increase the swelling of the proteins. The salt will shift the isoelectric point of the lean tissue to a lower pH, thus increasing the net negative charges resulting in enlargement of the space available for water absorption in the lean tissue (Rust 1987). By adding a phosphate with a known pH, the pH of the meat can be shifted upon phosphate dissociation and availability of hydrogen ions resulting in an

increase in water holding capacity (Hamm 1971). The phosphates have the ability to attach to positively charged sites of large molecules and alter that molecule's functionality which is important to the interaction of phosphates with proteins. Phosphates have been known to increase the ability of meat to hold water for many years (Swift and Ellis 1956).

As the temperature increases to 7 °C (45 °F), the remaining ice or water should be added and allowed to be absorbed by lean tissue. The fat meats and the other ingredients should be added next, while chopping continues to achieve a final emulsion temperature of 13 °C (55 °F) to 18 °C (64 °F) (Rust 1987). If all steps have been achieved successfully, the fat will be completely emulsified, meaning that soluble myofibrillar proteins have completely coated each particle of fat and during heat treatment the protein will denature and bind all the fat.

Emulsion Stability

If a stable emulsion is not achieved there will be evidence of unemulsified fat, unbound moisture or gelatin on the surface or interior of the final cooked product. The unemulsified fat may either be present as fat on the ends of the sausages (fat caps) or a thin coating of grease on the surface of the sausages. Townsend and others (1968) developed a method in which raw emulsion was placed in a hand stuffer and stuffed into a 7/8 x 4 inch polycarbonate tube. The tubes were subsequently heat processed in a hot water bath (48.8 °C) until an internal temperature of 68.8 °C was achieved. The liquid released during cooking was decanted into a 15 ml tube and the total volume of liquid, fat, gel-water, and proteinaceous solids were measured.

Rongey (1965) developed a similar method to determine emulsion stability. Raw emulsion is stuffed into a glass tube, cooked in a hot water bath, and centrifuged. The separated water and aqueous fat is measured to determine the percent separated water

and percent separated fat. The complete procedure is described in the materials and methods section.

To aid in the development of a stable emulsion, Monagle and others (1974) expressed that processing conditions must follow a stepwise temperature increase followed by a lowered relative humidity and an increased air flow in the smokehouse. If the heating conditions are extreme, protein molecules may not have time to align themselves in an ordered fashion, thus creating hydrated aggregates or precipitates which lack the continuous matrix of gels (Mulvihill and Kinsella 1987).

One of the most important features in the production of meat emulsions is to achieve high stability. When the stability of a meat emulsion is discussed, two determining properties must be considered: the water-holding capacity (WHC) of the meat (proteins) and the fat-holding capacity (FHC). The water-holding capacity is mainly responsible for the stability of the matrix.

Functional Properties of Proteins

Protein functionality is a general term that has been defined as any physicochemical property that affects the processing and behavior of protein systems as judged by the quality attributes of the final product (Kinsella 1976). Acton and Dick (1984) defined the properties of meat constituents that are important for raw materials to encompass that would be utilized through manufacturing phases that will give rise to processed meat products. The major functional properties are: (1) water-binding ability (or water-holding capacity); (2) fat stabilization (or fat emulsification); (3) particle-to-particle binding ability (or protein gelation); and (4) the development of desirable color properties.

To better understand emulsions (meat batters) accomplished through processing, it is necessary to understand the terminology that describes the events that lead to the formation of a three-dimensional matrix. Four terms are commonly used with the formation of emulsions: denaturation, aggregation, coagulation, and gelation. Denaturation is the process in which a protein or polypeptide is transformed from an ordered to a disordered state without rupture of covalent bonds (Scheraga 1961). Occasionally, the unfolding of the protein structure is considered part of denaturation. Aggregation is a general term referring to protein-protein interactions with formation of complexes of higher molecular weights (Hermansson 1979). Egelandsdal (1980) described that aggregation is usually controlled by a balance between attractive forces (i.e. hydrogen bonds, covalent bonds such as disulfide linkages, or hydrophobic associations) and repulsive forces (i.e. coloumbic forces which are affected by the net charge of the protein molecule or the ionic strength). Coagulation is defined as the random aggregation of already denatured molecules (Hermansson 1979) in which polymer-polymer interaction are favored over polymer-solvent reactions (Schmidt 1981). Hermansson (1979) defined gelation as an orderly aggregation of proteins, which may or may not be denatured, forming a three-dimensional network.

The theory of gelation began in 1948 with Ferry's classic explanation of the two-stage process of heat-induced aggregation of protein molecules that is (1) initial unfolding of protein molecules to expose the specific binding sites, and (2) aggregation to form a gel matrix. This process is more simply stated as:

Native protein → denatured protein (long chains) → aggregated protein (associated network)

Hermansson (1978) expanded on this theory when it was stated that contrary to coagulation, where aggregation of the protein molecules is random, gelation involves the formation of a continuous network exhibiting a certain degree of order. Gelation is dependent on the type and concentration of protein, the processing conditions used to induce gelation (heat or divalent cations), and the pH and ionic environment (Hermansson 1978; Schmidt 1981). Ziegler and Acton (1984) reported the pH of muscle may be 6.8-7.0 (pre-rigor processing) and 5.4-6.0 (post-rigor processing).

The main constituent involved in the formation of a three-dimensional matrix is the myofibrillar fraction. Xiong (1994) gave a thorough description of myofibrillar proteins and their implications for biochemical and functional properties in meat processing. The myofibrillar fraction can be divided into numerous proteins (as discussed previously in the muscle protein section), but is mainly made up of myosin and actin. Myosin is the predominant protein in prerigor meat, whereas actomyosin is the predominant protein complex in postrigor meat. Myosin contains two globular "heads" attached to the end of a rod-like "tail." The tail portion is composed of two helically interwoven polypeptide strands each containing one globular head. Actomyosin has a slightly larger axial ratio and is a complex of myosin, fibrous actin (F-actin), tropomyosin, the troponins, and the actinins.

The term comminution is defined by numerous authors as the process of reducing a material to a fine particle state. In comminuted processed meat, where more than 2 percent salt (translated into approximately 0.5 M sodium chloride in the aqueous phase) is normally added, myofibrillar structure initially swells and is then disrupted, producing actomyosin, myosin, and a variety of protein aggregates or complexes including intact myofibrils (Xiong 1994). Therefore, the myofibrillar system is more closely related to processed meats than is myosin.

Gelation of myofibrillar protein is perhaps the most important property that occurs in restructured, formed, and sausage products and is also responsible for texture, viscoelastic traits, juiciness, and stabilization of fat emulsions in processed products. Application of heat causes a series of events to occur in the myofibrillar proteins used in processed meats. Ziegler and Acton (1984) compiled the conformational changes which may occur during the thermal denaturation of actomysosin from various authors (Table 2.2).

Table 2.2. Conformational changes of actomyosin due to thermal denaturation (Ziegler and Acton 1984).

Temperature (°C)	**Protein(s) or segment involved**	**Description of events**
30 - 35	Native tropomyosin	Thermally dissociated from the F-actin backbone
38	F-actin	"Super" helix dissociated into single chains
40 – 45	Myosin	Dissociates into light and heavy chains
	Head	Possibly some conformational change
	Hinge	Helix to random coil transformation
45 - 50	Actin, myosin	Actin-myosin complex dissociates
50 - 55	Light meromyosin	Helix to coil transformation and rapid aggregation
> 70	Actin	Major conformational changes in the G-actin monomer

Protein-protein interaction is a functional event that can be related to structural integrity of meat products through orderly heat-induced aggregations. According to Acton and Dick (1984), these aggregations are two-fold, involving the head portion(s) of myosin at

temperatures between 30 °C and 50 °C and the rod segment in the temperature region above 50 °C.

The gelation phenomenon of myofibrillar proteins has been examined in model systems consisting of purified protein and salt in well-controlled ionic and pH environments (Yasui and others 1979; Samejima and others 1981; Li-Chan and others 1984, Li-Chan and others 1985; Egelandsdal and others 1986; Foegeding and others 1987; Wang and others 1990; Beuschel and others 1992; Wang and Smith 1994; Smith and Rose 1995; McCord and others 1998; Vittayanont and others 2001).

Yasui and others (1979) utilized isolated myosin in heat-induced gelation environments to reveal the physicochemical events occurring at the submolecular level during thermal denaturation. It was found that the myosin heads tended to aggregate upon low temperature heating (35 °C), while the tail portion of the myosin underwent a helix-coil transition at elevated temperatures. Samejima and others (1981) later used subfragments of myosin (globular heads of myosin and the myosin rod) to demonstrate two features of the heat induced gelation of myosin: aggregation and a three-dimensional network formation.

Salt extracts of beef round samples were researched to determine the emulsifying properties of muscle proteins (Li-Chan and others 1984) and investigate the relationship between functional and physicochemical properties of muscle proteins (Li-Chan and others 1985). It was determined that high temperature (greater than 45 °C) low pH (5.5) heating improved fat-binding and gelation. It was hypothesized that this occurrence was due to hydrophobic interactions.

Egelandsdal and others (1986) researched rheological measurements of myosin gels to determine the effect ionic strength, protein concentration, and addition of phosphates.

Heat-induced myosin gels of low (~0.24) ionic strength displayed non-linear viscolelastic behavior, while low ionic strength and low pH treatments resulted in stronger heat-induced gels. Protein concentration as well as heating rate of the myosin gels had a marked influence on rheological thermograms.

Foegeding and others (1987) evaluated the molecular interactions of myosin, fibrinogen, and myosin-fibrinogen in gels produced from porcine myosin and bovine fibrinogen. The myosin, fibrinogen, and myosin-fibrinogen formed gels at 70 °C. Moreover, the myosin and fibrinogen gels formed at 70 °C were stabilized by both noncovalent and disulfide bonds, while the myosin-fibrinogen gels consisted of noncovalent and disulfide bonds at °50 and 70 °C.

Techniques for the extraction of salt-soluble proteins discovered by Wang and others (1990) were utilized by Beuschel and others (1992), Smith and Rose (1995), McCord and others (1998), and Vittayanont and others (2001). Beuschel and others (1992) isolated chicken breast salt-soluble proteins to determine the functional performance of chicken salt-soluble protein and whey protein concentrate mixtures in a heat-induced meat protein gel model system. Smith and Rose (1995) evaluated the effect of sodium tripolyphosphate on chicken salt-soluble protein and whey protein concentrate in a model gel system. It was determined that the sodium tripolyphospahtes increased gel hardness, decreased expressible moisture, and enhanced the functionality of whey protein concentrate.

McCord and others (1998) extracted salt-soluble proteins from pre-rigor porcine semimembranosus muscle. These authors evaluated the gelling properties of the salt-soluble proteins as affected by the addition of whey protein concentrate, whey protein isolate, and soy protein isolate. The myosin heavy chain was observed to be the principal contributor to the gel network formation in all treatments. More recently, Vittayanont and

others (2001) utilized myosin extracted from chicken *Pectoralis Major* muscle and β-Lactoglobulin to investigate the aggregation and rheological properties of myosin-β-Lactoglobulin gel system.

Although much research has been conducted utilizing extractions of salt-soluble proteins in gel model systems, processed muscle foods (i.e. frankfurters) represent a more complex system in which myofibrillar proteins are mixed intimately with sarcoplasmic and stromal proteins as well as various lipids, minerals, sugars, and other additives. Due to the addition of the previously mentioned meat and non-meat ingredients, considerable deviations could exist between model gelation systems and meat processing systems. According to Xiong (1994), this deviation is true for highly comminuted and emulsified "gel" products (e.g., frankfurters) wherein the ability of a protein to gel is influenced by the fat content, the degree of emulsification, and the emulsion stability.

On the other hand, deviations between model gelation systems and meat processing systems are expected to be less because the salt extract at the junction of meat pieces is relatively pure, therefore protein gelation of the extract is subjected to fewer variables. Nonetheless, Xiong (1994) stated that it is doubtful whether the observations obtained from the model gelation studies with dilute myosin, actomyosin, or myofibrils would exactly duplicate the functionality of the proteins in meat processing systems.

Research on protein interaction has also been conducted by numerous authors in meat processing model systems (Townsend and others 1968; Lauck 1975; Jones and Mandigo 1982; Paulson and others 1984; Patana-Anake and Foegeding 1985; Su and others 2000).

Townsend and others (1968) developed a "bench top" method to evaluate emulsion stability of basic sausage formulations. This method utilized a formulation of 2.25 lb of lean

beef, 2.75 lb of pork trimmings, 1.25 lb of flaked ice plus seasoning, cure, sugar, and salt. The lean beef was ground through a 1.5875 cm (5/8 in.) and then through a 0.47625 cm (3/16 in.) grinder plate, while the pork trimmings were ground twice through a 1.27 cm (1/2 in.) grinder plate to obtain uniform mixing of fat and lean. The raw emulsion was placed in a hand stuffer and 34 gram samples of emulsion were stuffed into 7/8 x 4 inch polycarbonate tubes. The tubes were subsequently placed in a hot water bath and thermally processed to test emulsion stability.

Although these processing conditions may introduce slight variation from the meat ingredient utilized, a better applied representation of the protein interaction is revealed that will occur in the commercial product. It is of importance to minimize the pH and muscle variation of the raw meat ingredient and moisture, fat, protein, and salt of the meat batter produced.

Non-Meat Ingredients

A variety of ingredients are encompassed by the term "non-meat ingredients" when processed meat formulations are developed. Non-meat ingredients are utilized to impart unique and specific characteristics of processed meat products. Basic non-meat ingredients include, but are not limited to, salt, sugar, nitrite, sodium erythorbate, sodium phosphate, liquid smoke, etc. Each ingredient plays a special role in processed meat products whether it be the rate of cure acceleration, stabilization of color, modification of color and texture, or a reduction in shrinkage during heat processing. Each ingredient is formulated by governmental regulations, ingredient functionality, or consumer acceptance.

A growing practice in the meat industry is the use of artificial meat-like products which have controlled texture, flavor, color, and nutritive value. These meat-like products

have been marketed to substitute directly for meat to economically extend the amount of finished product produced as well as improve the texture and quality characteristics of the final product.

Meat Curing Ingredients

Certainly the most common and widely utilized non-meat ingredient is salt. Salt, or sodium chloride, is used in curing and sausage formulations to impart a desirable flavor while also possessing some preservative effect (Romans and others 1985). In sectioned and formed meat products, salt extracts myofibrillar proteins, and thus gives binding strength at the junction between adjacent pieces of meat (Pearson and Tauber 1984). Furthermore, in comminuted muscle products, the solubilization of the myofibrillar proteins aids in the water binding abilities of the proteins which in turn decreases cooking loses. The amount of salt added may vary from product to product, but generally is about 2-2½ percent (Cassens 1994). For related health reasons, consumers have attempted to reduce sodium intake, thus the level of sodium has been reduced in most formulations through the years. Due to the harsh, dry, salty final product as a consequence of the use of salt alone, it is generally used in combination with sugar or an alternative sweetener (i.e. dextrose, corn syrup, corn syrup solids, etc.).

Sugar, or some other sweetener, is normally included in curing and processed product formulation for flavor (Pearson and Tauber 1984). Sugar acts by counteracting the harsh hardening effects of salt by preventing some of the moisture removal and by a direct moderating action on flavor (Kramlich and others 1973). The type of sugar or sweetener used may influence color development (that is darkening or browning) as the meat is exposed to heat during preparation from a carmelization reaction (Cassens 1994). The

sugars most frequently used are sucrose and dextrose and their derivatives (Romans and others 1985).

The function of nitrite in meat curing is four-fold: (1) to stabilize the color of the lean tissue, (2) to contribute to the characteristic flavor of cured meat, (3) to inhibit growth of a number of food poisoning and spoilage microorganisms, and (4) to retard oxidative rancidity of fatty acids (Pearson and Tauber 1984). The stabilization of the cured color occurs when nitrite is converted to nitric oxide and water. The nitric oxide combines with the myoglobin in the lean tissue to form nitric oxide metmyoglobin. Under favorable conditions the nitric oxide metmyoglobin is converted to nitric oxide myoglobin. During the heat processing of the processed product a stable pink pigment (nitrosyl-hemochromogen) is established.

The purpose of sodium erythorbate in formulations is to increase the reduction of sodium nitrite to nitric oxide, thus accelerating the cure reaction (Hollingsworth 1981). The antioxidant properties of erythorbate not only prevent development of rancidity, but also prevent color fading of sliced meats when exposed to light. As erythorbate is depleted, the heme pigments are degraded and apparently catalyze lipid oxidation (Pearson and Tauber 1984).

The primary purpose of using phosphates is to increase the water holding capacity of cured meat products and therefore, reduce the degree of "purge" in cooked products (Townsend and Olson 1987). Phosphates are beneficial to consumer's eating pleasures such as improved flavor of meat as a result of retention of natural juices, reduction of oxidative rancidity, and improved color retention.

Animal Protein Sources

Although there are three main groups of animal proteins (myofibrillar proteins, sarcoplasmic proteins, and stromal proteins) utilized in the production of processed meat products, animal protein sources such as collagen, blood plasma, and milk proteins can also be utilized in the production of processed meat products. Collagen, blood plasma, and milk proteins can assist in the binding of added water in meat formulations, texture enhancement of the final product, and the reduction of the overall fat content in processed meat products.

Collagen

Collagen is found in all animal tissues and is the main component of connective tissue. Collagen and the utilization of collagen in meat systems were discussed in detail in the previous sections.

Blood Plasma

Blood proteins have been used for many years as a functional and nutritional food ingredient in many countries of the world. Blood collected from livestock in accordance with USDA regulations (USDA 2002b) may be used in non-specific meat products intended for human consumption. Blood must be processed from a liquid form to a shelf-stable powder form (Figure 2.11). Due to the color and functional properties, blood plasma is the portion of blood that is of greatest interest.

The collection method was outline by Wismer-Pedersen (1979) and Knipe (1988). Blood from numerous animals is pooled in one container until inspectors have approved every carcass from which the blood was collected. Anticoagulants are used to prevent coagulation by binding calcium ions in the blood with sodium citrate and various phosphates. The collected blood should be chilled as rapidly as possible after collection to

2-4 °C (35-40 °F) to minimize microbial growth. Whole blood is separated into plasma and red cells by centrifugation. Blood is then dried by one of the following methods: spray drying, freeze drying, ball drying, or roller drying. Blood is dried to decrease the water content from 90 percent to 5-10 percent water in the final product. The final product (e.g. plasma) should have a tan color.

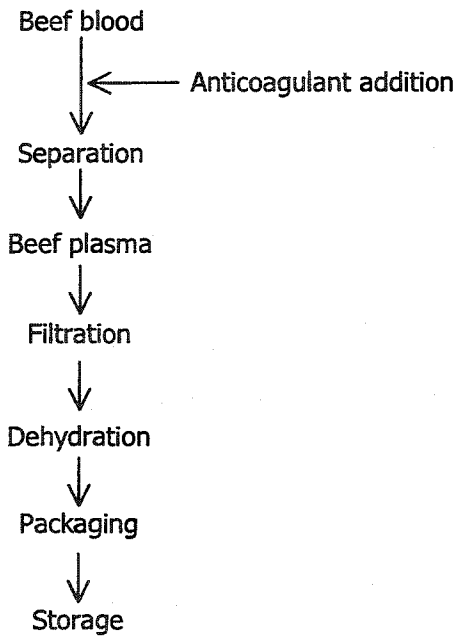


Figure 2.11. Schematic of the production of beef blood plasma (Provided by Proliant Inc.).

Many researchers have studied the use of blood plasma in meat systems. Caldironi and Ockermann (1982) reported that a bologna sausage produced with 10 percent of the meat replaced by plasma and globin protein was ranked as acceptable to a sensory panel. Murmann and Wenzel (1986) reported the production of frankfurter-type sausage products in which blood plasma concentrate was used to replace ice and/or lean meat. The authors reported an increase in pH with increasing plasma concentrate content. The addition of

blood plasma reduced firmness of the final product and sensory deviations from the control were noticeable at a blood plasma concentrate content of 6.75 percent.

Bovine plasma protein was utilized at three levels (1.5, 2.5, and 3.5 percent) in ground beef patties to research texture, color, and sensory characteristics (Guzmań and others 1995). The lightness (L* values) of uncooked beef patties generally decreased with increased blood plasma. Cooking losses were lower ($P<0.05$) for beef patties with 3.5 percent blood plasma due to the gelling properties that have the ability to entrap moisture and fat released from the meat during heating. The a* values of cooked treatment patties were not different ($P<0.05$) from those of cooked controls. The L* values and b* values generally decreased as the blood plasma content increased.

Cofrades and others (2000) researched the effect of plasma protein and soy fiber content on bologna sausage properties. The authors determined that higher soy fiber and plasma contents favored the formation of harder, chewier structures with improved fat and water binding properties. Overall, plasma protein influenced binding and textural properties more than soy fiber.

Blood plasma has been shown to have good water binding properties, but its use as a lean meat replacement for processed meat products is limited by the reduction in firmness.

Milk Proteins

Milk proteins can be used as a fat replacement option. Some examples used in meat products are non-fat dry milk, coprecipitates, whey proteins and caseinates (Mandigo and Eilert 1994). The two most commonly utilized types of milk proteins are caseins and whey proteins. Caseins represent 82 percent of the total milk protein and whey proteins

represent 18 percent. Milk proteins provide direct fat binding and indirect water binding (Hoogenkamp 2001).

Gonzalez (1998) researched the effect of milk protein on the properties of light chicken bologna. The author revealed that 1 percent or 2 percent milk protein could be successfully incorporated into light bologna formulations. The overall affect of adding milk protein to the light bologna formulation resulted in improved fat, moisture and protein content without causing measurable instrumental and sensory texture differences from the control.

Whey protein is actually a by-product of cheese production. The basic schematic for the production of whey protein is displayed in Figure 2.12. Whey protein is specially designed to form a firm, elastic, salt stable high gel strength in meat and emulsion based products. Due to steep price increases and availability of other highly functional protein sources, the utilization of milk proteins has decreased throughout the years.

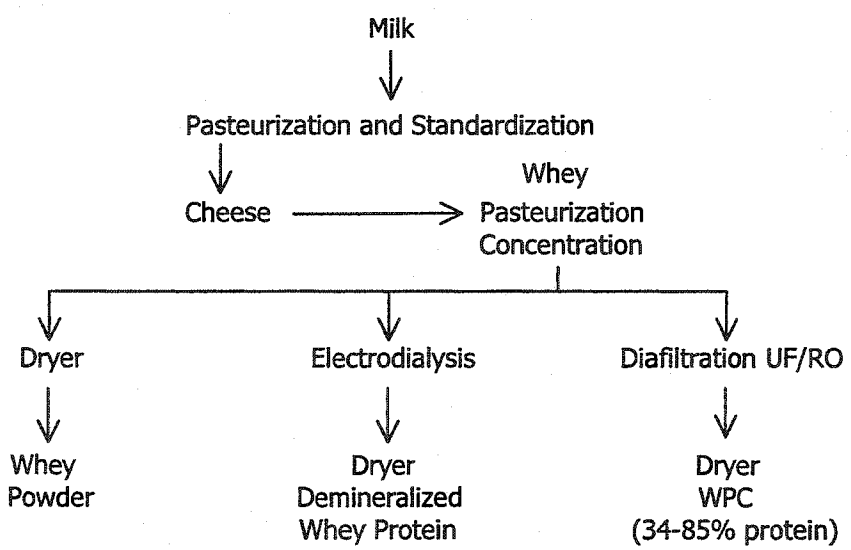


Figure 2.12. Schematic of the production of whey protein concentrate (Provided by Proliant Inc.).

Carbohydrate Sources

There are a wide variety of carbohydrates available to meat processors to enhance the production of processed meat products. Starches, konjac flour, carrageenan, and xanthan gum are a few of the most commonly utilized carbohydrate sources in meat systems.

Starches

Starches can be obtained from a variety of sources and can have a wide functionality range. Starches are the most widely used carbohydrate because of economics and availability. The most common starches in the meat industry originate from potato, corn, wheat, tapioca, and rice. Starches are used in meat systems to modify final product texture, bind water and fat, and increase emulsion stability. Starches generally provide a firmer texture in meat products. Starches can also bind two to four times their weight in water which facilitates an increase cook yield of the final meat product. Modified starches are also used in meat formulations. The modification of starches is performed to enhance the properties of the native starches. According to the USDA (1998), a modified food starch is a material consisting of starch which has been hydrolyzed by acid or other acceptable means.

Konjac Flour

Konjac is a generic name for the flour formed from grinding the root of the *Amorphophallus konjac* plant (Elephant yam). Konjac flour is unique as it has the ability to form a heat stable gel when treated with an alkali to remove the acetyl side groups. Konjac flour is used at very low levels in meat products for water retention and textural modification which mimics the sensory properties of fat (Lamkey 1998). The USDA allows the use of konjac flour in meat and poultry products in which starches or vegetable flours

are permitted at the level of 3.5 percent in cooked sausage such as frankfurters and bologna USDA (1998).

Carrageenan

Carrageenan is a hydrocolloid originating from selected red seaweed. Carrageenan has the ability to retain high levels of moisture, approximately twenty to twenty-four times its weight in water and improve the texture in meat products. There are three general types of carrageenans (kappa, iota, and lambda) which are categorized by their gelling properties. Kappa and iota carrageenan have the ability to form gels that are thermally reversible. Kappa carrageenan forms strong and brittle gels, while iota carrageenan forms a weak and elastic gel. Lambda carrageenan does not form gels, but can increase viscosity. In most cases carrageenan is used at low levels (less than 1 percent) as a thickening and gelling agent (Lamkey 1998).

Xanthan Gum

Xanthan gum is a product of microbial fermentation from a bacteria called *Xanthomonas campestris*. Xanthan gum is soluble in hot or cold water and has the ability to produce high viscosity/strong gels at low concentrations. Xanthan gum also functions well in the presence of salt. Furthermore, when xanthan gum is combined with other gums (i.e. guar gum), it has the ability to increase viscosity of the solution (BeMiller and Whistler 1996). The USDA allows sausage products to contain up to 0.15 percent xanthan gum in the finished product (USDA 1998).

Vegetable Protein Sources

Throughout the years the production of vegetable proteins to be utilized in processed meat products has expanded from soy protein to other protein sources such as oat and fruit proteins.

Soy Protein

Soy protein is produced from the soybeans of soybean plants (*Glycine max*) which belong to the legume family. The soybean plant was first introduced to America from Asia in 1804 (Hoogenkamp 1998). The protein content of the seed is approximately 40 percent, but after the hulls and the oil are removed the remaining defatted flake has a protein content of approximately 50 percent. Soybeans are refined by processing facilities to yield three major groups of soy proteins based on protein content: soy flours and grits, soy protein concentrate, and soy protein isolates. Table 2.3 displays the composition of the soy proteins that are commercially available (Endres 2001).

Table 2.3. Composition (%) of soy protein products (Endres 2001).

Composition	**Defatted Flours and Grits**		**Concentrates**		**Isolates**	
Constituent	As is	mfb[a]	As is	mfb[a]	As is	mfb[a]
Protein (N x 6.25)	52 - 54	56 - 59	62 - 69	65 – 72	86 - 87	90 - 92
Fat (pet. Ether)	0.5 - 1.0	0.5 - 1.1	0.5 - 1.0	0.5 - 1.0	0.5 - 1.0	0.5 - 1.0
Crude fiber	2.5 - 3.5	2.7 - 3.8	3.4 - 4.8	3.5 - 5.0	0.1 - 0.2	0.1 - 0.2
Soluble fiber	2.0	2.1 - 2.2	2.0 - 5.0	2.1 - 5.9	< 0.2	< 0.2
Insoluble fiber	16.0	17.0 - 17.6	13.0 - 18.0	13.5 - 20.2	< 0.2	< 0.2
Ash	5.0 - 6.0	5.4 - 6.5	3.8 - 6.2	4.0 - 6.5	3.8 - 4.8	4.0 - 5.0
Moisture	6 - 8	0	4 - 6	0	4 - 6	
Carbohydrates (by difference)	30 - 32	32 - 34	19 - 21	20 – 22	3 - 4	3 - 4

[a] mfb: moisture-free basis

Soy flours and grits are the least refined forms of soy protein products used for human consumption which creates flours highly variable in terms of quality. Soy flours may vary in fat content, particle size, and degree of heat treatment. Soy flours are high in oligosaccharides, the soluble carbohydrates that give flours the beany flavor that is objectionable to consumers. Soy flours and grits are still widely utilized in baked goods, snack foods, and pet foods or, in general, in applications where high flavor profile isn't an issue. Textured soy flours were an early attempt at simulating the texture of meat products (Central Soya Company, Inc. 1998). Soy flour has a hydration ratio of approximate 2 parts water:1 part soy flour.

Soy protein concentrates are prepared from dehulled and defatted soybeans by removing most of the water-soluble, non-protein constituents. In general, soy protein concentrates are low in flavor, high in protein, economical, low in sodium, high in dietary fiber, and exhibit the functional characteristics desired by many food processors. Soy protein concentrates have been redesigned through the years and are currently available in powdered, flaked and crumbled form to accommodate the appropriate processing procedures and final product characteristics desired by both food producers as well as consumers. Soy protein concentrate has a hydration ratio of 3 parts water:1 part soy protein concentrate.

Soy protein isolates are the most highly refined soy protein products commercially available. Soy protein isolates are produced through standard chemical isolation of the soybeans protein. Soy protein isolates are low in flavor, extremely high in protein, relatively expensive, and contain no dietary fiber. The major applications for soy protein isolates have been in dairy substitution, such as in infant formulas and milk replacers. If soy protein

isolates are utilized in meat systems, soy protein isolate has a hydration ratio of 6 parts water:1 part soy protein isolate.

Due to the varying protein content, the USDA has different regulations on the amount that is permitted in processed meat products. Soy flours and soy protein concentrates are approved in sausages at 3.5 percent individually or collectively with other binders. Soy protein isolate are approved at 2 percent individually (USDA 1995).

Wheat

Textured wheat proteins have been proven effective in a meat system. Textured wheat protein is produced through a proprietary process in which powdered wheat gluten is extruded. The final product has the structure and texture of meat products when rehydrated. The protein's bland flavor and light color offers food formulators several benefits. Flavor components can be added to make the wheat gluten taste like chicken, meat, or fish. Although uncolored, the wheat protein has the appearance of chicken. Various colors can be added to it so that it resembles various meats. Textured wheat proteins are used between 30-40 percent for extended products and at 100 percent for pure vegetarian products (Brandt 1999). Textured wheat protein utilized at 30 percent in chicken nuggets had the highest score for taste and texture, followed by the treatment containing 20 percent textured wheat protein.

Wheat proteins, an abundant and economical source of food protein, have the unique ability to form a viscoelastic mass of gluten when mixed with water (Pritchard and Brock, 1994) and thus have potential as non-meat additives in meat products. Siegel and others (1979) attributed the ability of wheat gluten to bind meat pieces to its ability to interact with myosin. Consequently, wheat gluten holds potential for use in low-fat and no-fat meat products.

Oat

Oat products are milled in a variety of different ways and they can be made into a wide range of products to accommodate the needs of the food industry. McKechnie (1983) described products such as rolled oats, oat flour, and oat fiber. Oat fiber is derived from the oat hull and is mostly insoluble.

Steenblock (1999) researched the quality characteristics of adding oat fiber at three levels (1-3 percent of the total formulation weight) to light bologna and fat-free frankfurters. The author determined that the 3 percent addition of oat fiber produced greater processing yields for both bologna and frankfurters and also reduced package purge. The oat fiber treatments resulted in greater product hardness as measured by both instrumental and sensory evaluations.

Fruit

Fruit sources have been researched in an attempt to satisfy red meat's quest to discover a fat replacer that retains the qualitative aspects of fat and is cost effective. A 100 percent blended fruit powder, made from pears, apples, and plums, has proven to be a multifunctional ingredient that increases moisture in meat applications while contributing to the flavor profile. The use of a blended fruit powder at 1-2 percent (dry basis) levels in meat patties increased yield, retained moisture, improved texture, and lowered the fat content. The fruit sugars add sweetness and encourage surface browning in products. The fruit acids, such as malic acid, also contribute to flavor enhancement. Nutritionally, blended fruit powder contributes vitamins, fiber, and phytochemicals that can be viewed as beneficial by consumers (Broihier 2000).

Another fruit source that has been suggested is plum purée. Small amounts of formulated USDA plum purée addd to ground beef patties increased the moisture of the

finished product by 15-18 percent. In addition, the products' cooked weights increased while the fat content decreased by approximately 40 percent (Nunes 1999).

USDA Regulations on Restricted Ingredients

The regulatory process has limited the use of some non-meat ingredients to a level in which an effect would be produced and to minimize any possibility that any of the substance used may be harmful to human health (Cassens 1994). The most widely established restricted ingredients are nitrate, nitrite, ascorbate, erythorbate, phosphates, antioxidants (i.e. butylated hydroxyanisole, butylated hydroxtoluene, tertiary butylhydroquinone, propyl gallate, etc.), sweeteners (i.e. corn syrup solids), binders and extenders (i.e. soy concentrate, isolated soy protein, etc.), and flavorings. The permitted levels that have been established by the USDA and enforced by the Food Safety and inspection Service (FSIS) are defined in Table 2.4 (USDA 1995).

The USDA also regulates the amount of binders or extenders that can be utilized in processed meat products. The regulated levels were discussed in previous sections. Binders and extenders are defined by the USDA (USDA 1995) as:

> *Binder*: "An additive used to improve the binding of lean meat or poultry or meat and/or poultry mixture. Binders have strong affinity for water, therefore misuse of binders may cause the product to be adulterated with excess water"

> *Extender*: "An additive that increases the weight and changes texture of meat and poultry products, i.e. cereal, starches, etc."

Table 2.4. Levels of the most commonly used restricted ingredients (USDA 1995).

Curing Agent(s)	**Maximum Limit**			
	Immersion Cured	*Massaged or Injected*	*Comminuted*	*Dry Cured*
Sodium Nitrite	200 ppm	200 ppm	156 ppm	625 ppm
Potassium Nitrite	200 ppm	200 ppm	156 ppm	625 ppm
Sodium Nitrate	700 ppm	700 ppm	1718 ppm	2187 ppm
Potassium Nitrate	700 ppm	700 ppm	1718 ppm	2187 ppm

Cure Accelerator(s)	**Maximum Limit**
Sodium Ascorbate	547 ppm
Sodium Eythorbate	547 ppm

Phosphate(s)	**Maximum Limit**	
	Massaged or Injected	*Comminuted*
Phosphates	5000 ppm	0.5% of the finished product weight

Antioxidant(s)	**Maximum Limit**		
	Dry Sausage -calculated on total weight of the product-	*Dried Meats -calculated on total weight of the product-*	*Fresh Sausage -calculated on fat content-*
Butylated Hydroxyanisole (BHA)	0.003%	0.01%	0.01%
Butylated Hydroxtoluene (BHT)	0.003%	0.01%	0.01%
Propyl Gallate (PG)	0.003%	0.01%	0.01%
Combination	0.006%	0.01%	0.02%

Rheology

The development of a desirable comminuted meat product is due to the functionality of the gelling properties of muscle components to produce desirable sensory texture and stabilize fat and water. Achieving the desired textural quality of food has important economic considerations. To measure this desirability, rheological science is applied to determine ingredient functionality as well as evaluate the food texture by correlating the rheology data to sensory data. Rheology has been defined as the manner in which materials respond to applied stress or strain (Steffe 1996).

Stress is the force per unit area and is achieved when a force is applied uniformly to a body with area (Bourne 2002). Bourne (2002) also stated that if the sample is uniform is shape and composition and the deformation is small, it is generally assumed that the stress is evenly distributed throughout the sample. Stress is most commonly applied to foods in compression but it can also be applied in tension or shear (sideways or lateral). Strain refers to the change in size or shape of a material when it is subjected to a stress. Stress is always a force measurement and strain is always based on measurement of a distance.

More specifically, the study of material deformation and flow which includes what is termed "small-strain" testing (deforming a small percent of that required to break the sample) and "large-strain" testing (deforming to the point of permanent structural change) (Scott-Blair 1969). Large-strain instrumental testing is required to consistently correlate with sensory texture (Hamann and Webb 1979; Montejano and others 1985), which is the critical base in evaluating desirable gel-forming functionality (Hamann 1988).

Szczesniak (1963) divided instrumental methods for texture measurement into three classes: fundamental tests, empirical tests, and imitative tests. Fundamental tests measure the ultimate strength of a structure. This test is used in engineering applications where

structures should not break under normal conditions. Therefore, fundamental tests correlate poorly with sensory evaluations of the textural properties of foods due to the limited force that is used to break food into pieces during chewing. Empirical tests use puncture, shear, and extrusion tests to correlate to textural quality on a limited number of foods. Imitative tests are used to mimic conditions that food is subjected to in the mouth and on the plate.

The data generated and interpreted from instrumental and sensory evaluations of food texture is referred to as Texture Profile Analysis (TPA). Texture profile analysis is an example of imitative texture measurement. These tests imitate the conditions to which the food material is subjected in true consumption scenarios. Bourne (2002) discussed the advantages of imitative tests as: (1) the test closely duplicates mastication or other sensory methods, (2) the test correlate well with sensory methods, and (3) the test provides a complete measurement of texture.

Uniaxial compression tests are generally utilized to mimic or imitate the mastication and consumption of food. The sample is compressed in one direction and is unrestrained in the other two dimensions. For solid foods, the uniaxial compression test can be divided into a nondestructive or destructive class. The nondestructive uniaxial compression test applies a minimal compression force to ensure there is no fracture, breaking, or any other irreversible damage done to the sample. A nondestructive uniaxial compression test may apply a compression up to 50 percent of the sample's original height to determine the texture attributes. The destructive uniaxial compression test applies an increased compression force to a level that ensure the sample will break causing irreversible damage to the sample. A destructive uniaxial compression test may apply a compression greater than 50 percent of the sample's original height to determine the texture attributes

Steffe (1996) referred to texture as the human sensation of food derived from its rheological behavior during mastication and swallowing. A generalized texture profile curve is illustrated in Figure 2.13 (Bourne 1978; Steffe 1996).

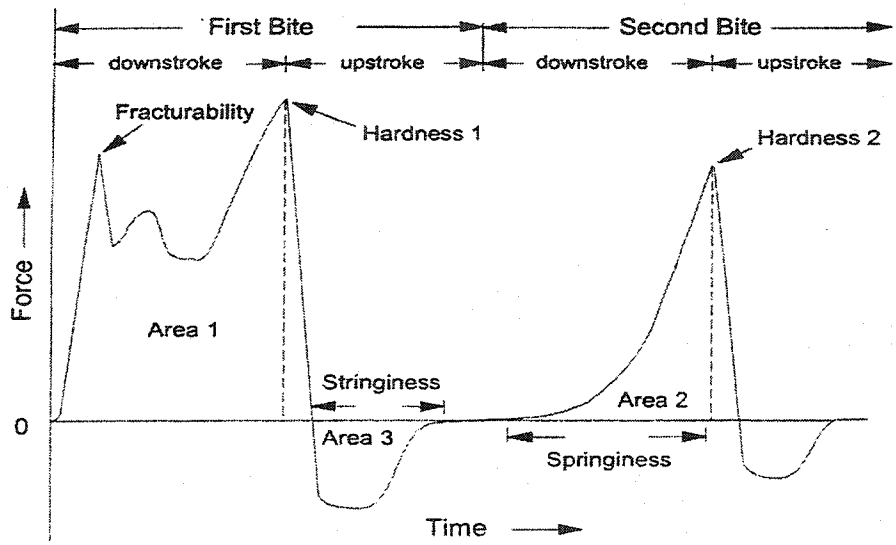


Figure 2.13. Generalized texture profile curve (Bourne 1978; Steffe 1996).

Bourne (1978) and Steffe (1996) reported a generic texture profile analysis of a frankfurter (Figure 2.14). The frankfurter deformed very easily (low initial slope) and displayed a questionable fracturability peak, no adhesiveness, and moderate cohesiveness and springiness (Bourne 1978).

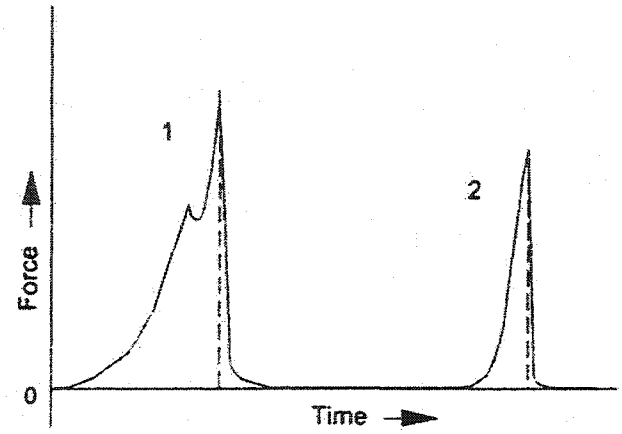


Figure 2.14. Texture profile analysis of a frankfurter (Steffe 1996)

The technique of texture profile analysis usually uses the Instron Universal Machine or the TA.XT2i Texture Analyzer where a food sample (usually a 1 cm sample) is compressed two times, usually to 80 percent of its original height. The compression is achieved using parallel plates where one plate is stationary and the other plate moves with a reciprocating linear cyclical motion (Steffe 1996). This technique is described as a two-bite compression system, where the first and second compression cycles are referred to as the first bite and second bite, respectively. Szczesniak and others (1963) and Bourne (1978) defined various textural parameters produced from a force-time curve, while Civille and Szczesniak (1973) defined the sensory parameters from a trained panel (Table 2.5).

Payne (1993) evaluated eleven varieties of commercial franks to provide benchmark data for further research. Texture profile analysis by compression to 25, 50, and 75 percent for cold and reheated franks was performed to determine the compression quantity that best suited the texture attribute. Compression at 75 percent gave the best separation of

franks for hardness and springiness, while compression at 50 percent gave the best separation of franks for cohesiveness, gumminess, and chewiness.

Table 2.5. Texture Profile Analysis and sensory technique definitions for texture parameters.

Texture attribute	**Texture Profile Analysis definition** [a]	**Sensory definition** [b]
Fracturability	Force at the first major drop in force curve	Amount of force required to fracture the material
Hardness 1	Force at maximum compression during first bite	Amount of force exerted by molar teeth needed to break the sample for the first bite
Adhesiveness	Represents the work, caused from a tensile force, needed to pull food apart and separate it from the compression plates	Amount of work necessary to overcome the attractive forces of the sample and the teeth
Hardness 2	Force at maximum compression during the second bite	Amount of force exerted by molar teeth needed to break the sample for the second bite
Springiness	Distance or length of compression cycle during the second bite	Rate of recovery of a material after deformation
Cohesiveness	The ratio of the positive force area during the second compression to that during the first compression (Area 2/Area 1)	Degree to which a substance can be compressed before it breaks
Gumminess	The product of hardness 1 times cohesiveness	Energy required to disintegrate a sample to a state ready for swallowing
Chewiness	The product of gumminess times cohesiveness times springiness	Energy required to masticate a sample to a state ready for swallowing

[a] Szczesniak and others (1963) and Bourne (1978)
[b] Civille and Szczesniak (1973)

The puncture test measures the force required to push a punch or probe into a food. A punch is mounted in an instrument (i.e. an Inston or TA.TX2 machine) that automatically draws out a force-distance or force-time curve. Bourne (2002) characterized the test by (1) a force measuring instrument, (2) penetration of the probe into the food causing irreversible crushing of the food, and (3) the depth of penetration is usually held constant. During the first stage, the sample is deforming under the load but there is no puncturing of the tissues. This stage ends abruptly when the punch begin to penetrate into the food, which is represented by a sudden change in slop called the yield point. The yield point marks the instant when the punch begins to penetrate into the food, causing irreversible crushing of the underlying tissues.

A true puncture test assumes that the sample size is so much larger than the punch that no difference in the puncture force will be found if the sample is made even larger. Bourne (2002) calls this assumption "semi-infinite geometry." It is generally accepted that the diameter of the sample should be at least three times the diameter of the punch. The punch will only penetrate a small distance into the food relative to the size of the food and a solid base support plate is necessary.

In conclusion, numerous texture characteristics can be measured through the use of instrumental techniques. The correlation of instrumental results to sensory results can supply food producers with opportunity to test new cost reducing formulations while maintaining product quality characteristics.

References

Aberle ED, Forrest JC, Gerrard DE, Mills EW. 2001. Principles of Meat Science. 4th ed. Dubuque, IA: Kendall/Hunt Pub. Co.

Aberle ED, Mills EW 1983. Recent advances in collagen biochemistry. Proc. Recip. Meat Conf. National Live Stock and Meat Board, Chicago, IL. 36:125-130.

Acton JC, Dick RL. 1978. Effect of skin content on some properties of poultry meat loaves. Poultry Sci. 57(5):1255-1259.

Acton JC, Dick RL. 1984. Protein-protein interaction in processed meats. Proc. Recip. Meat Conf. National Live Stock and Meat Board, Chicago, IL. 37:36-42.

Ambrosiadis J, Wirth F. 1984. Comminution of connective tissue and temperature pattern in the manufacture of frankfurter-type sausages. Fleischwirtschaft. 64(8):945-950.

Anonymous, 1998. United States leads world meat stampede. In: Worldwatch Press Briefing on the Global Trends in Meat Consumption. Available from: <www.worldwatch.org.>. July 2,1998.

Asghar A, Henrickson RL. 1982. Functional properties of food-grade bovine hide collagen in coarse bologna. II. Effect on different protein fractions. J. Food Quality. 5(4):271-284.

Bailey AJ. 1984. The chemistry of intramolecular collagen. In: Bailey AJ, editor. Recent Advances in Chemistry of Meat. London: Royal Soc. Chemistry.

Bailey AJ. 1987. The biological diversity of collagen: A family of molecules. In: Pearson AM, Dutson TR, Bailey AJ, editors. Advances in Meat Research. New York, NY: Avi Publishing Co. Inc. 4:1-17.

Bailey AJ. 1989. The chemistry of collagen crosslinks and their role in determining meat texture. Proc. Recip. Meat Conf. National Live Stock and Meat Board, Chicago, IL. 42:127-136.

Bailey AJ, Light ND. 1989. Connective tissue in meat and meat products. London: Elsevier Appl. Sci. P 225-247.

Bandman E. 1987. Chemistry of animal tissues. In: Price JF, Schweigert BS, editors. The Science of Meat and Meat Proteins. 3rd ed. Westport, CT: Food and Nutrition Press, Inc. P 61-102.

BeMiller JN, Whistler RL. 1996. Carbohydrates. In: Fennema OR editor. Food Chemistry 3rd Edition. New York, NY: Marcel Dekker, Inc. P157-223.

Bernal VM, Stanley DW. 1987. Stability of bovine muscle connective tissues. J. Food Sci. 52(4):876-878.

Beuschel BC, Partridge JA, Smith DM. 1992. Insolubilized whey protein concentrate and/or chicken salt-soluble protein gel properties. J. Food Sci. 57(4):852-855.

Boedtker H, Doty P. 1956. The native and denatured states of soluble collagen. J. Am. Chem. Soc. 78:4267.

Bourne MC. 1978. Texture profile analysis. Food Technol. 32(7):62-66, 72.

Bourne MC. 2002. Food Texture and Viscosity: Concepts and Measurements. Academic Press, San Diego, CA.

Brandt LA. 1999. Specialty wheat protein a "meaty" addition. Prepared Foods. May: 83.

Broihier RD. 2000. Meat gets fruity. Food Proc. Sept:66-68.

Caldironi HA, Ockermann HW. 1982. Incorporation of blood proteins into sausage. J. Food Sci. 47:405-408.

Calhoun CM, Eilert SJ, Mandigo RW. 1996a. Connective tissue/acidic phosphate preblend effects on reduced fat frankfurters. J. Food Sci. 61(2):459-464.

Calhoun CM, Eilert SJ, Mandigo RW. 1996b. Characteristics of low-fat, high-added-water frankfurters manufactured with preblends of connective tissue and alkaline phosphates. J. Muscle Foods. 7(4):471-487.

Campbell RE, Kenney PB. 1994. Edible by-products for the production and processing of muscle foods. In: Kinsman DM, Kotula AW, Breidenstein BC, editors. Muscle Foods: Meat and Poultry and Seafood Technology. New York, NY: Chapman and Hall. P 79-105.

Carpenter JA, Wiley EL, Reagan JO, Campion DR. 1979. Relationship of collagen content to functional properties of sausage meats. In: Carpenter JA, editor. 21st Proceeding of Meat Science Institute. P 71-74.

Cassens RG. 1987. Structure of muscle. In: Price JF, Schweigert BS, editors. The Science of Meat and Meat Proteins 3rd ed. Westport, CT: Food and Nutrition Press, Inc. P 11-59.

Cassens RG. 1994. Meat Preservation: Preventing Losses and Assuring Safety. Food & Nutrition Press, Inc., Trumbull, CT.

Central Soya Company, Inc. 1998. The protein book (http://www.centralsoya.com) Central Soya Company, Inc. Fort Wayne, IN.

Chavez J, Henrick RL, Rao BR. 1985. Collagen as a hamburger extender. J. Food Quality. 8(4):265-272.

Civille GV, Szczesniak AS. 1973. Guidelines to training a texture profile panel. J. Texture Stud. 4(2):204-223.

Cofrades S, Guerra MA, Carballo J, Fernández-Martín F, Jiménez Colmenero F. 2000. Plasma protein and soy fiber content effect on bologna sausage properties as influenced by fat level. J. Food Sci. 65(2):281-287.

Copenhaver WM, Kelly DE, Wood RL. 1978. Muscle. In: Bailey FR, editor. Bailey's Textbook of Histology 17th ed. Baltimore: Williams and Wilkins Co. 4:240-278.

Creighton TE. 1993. Physical and chemical properties of soluble proteins. In: Proteins: Structures and Molecular Properties. New York, NY: W.H. Freeman and Company. P 261-328.

Delmore RJ, Mandigo RW. 1994. Modified pork connective tissue for use in low-fat high added water frankfurters [abstract]. In: IFT Annual Meeting Book of Abstracts; 1994 June 25-29; Atlanta, GA. Chicago, IL.: Institute of Food Technologists. Abstract nr 47D-27.

Dutson TR. 1976. Biosynthesis and structure of collagen. Proc. Recip. Meat Conf. National Live Stock and Meat Board, Chicago, IL.Proc. 29:336-349.

Eastoe JE. 1967. Composition of collagen and allied proteins. In: Ramachandran, GN, editor. Chemistry of Collagen. New York, NY: Academic Press Inc. P 1-67.

Egelandsdal B. 1980. Heat-induced gelling in solutions of ovalbumin. J. Food Sci. 45(3):570-573,581.

Egelandsdal B, Fretheim K, Samejima K. 1986. Dynamics rheological measurements on heat-induced myosin gels: Effect of ionic strength, protein concentration and addition of adenosine triphosphate or pyrophosphate. J. Sci. Food Agric. 37(9):915-926.

Eilert SJ, Calhoun CM, Mandigo RW. 1996a. Phosphate type, concentration and preblend duration to improve water holding capacity of beef connective tissue. J. Muscle Foods. 7(2):255-269.

Eilert SJ, Mandigo RW, Sumner SS. 1996b. Phosphate and modified beef connective tissue effects on reduced fat, high water-added frankfurters. J. Food Sci. 61(5):1006-1011, 1029.

Eilert SJ, Mandigo RW. 1993. Procedure for soluble collagen in thermally processed meat products, J. Food Sci. 58(5):948-949.

Endres JG. 2001. Soy Protein Products: Characteristics, Nutritional Aspects, and Utilization. Revised and expanded ed. Champaign, IL: The American Oil Chemists' Society Press.

Eyre DR. 1980. Collagen: Molecular diversity in the body's protein scaffold. Science. 207(4437):1315-1322.

Ferry JD. 1948. Protein gels. Adv. Protein Chem. 4:1-78.

Finley E, Price R. 1994. International Agriculture. Albany, NY: Delmar.

Foegeding EA, Dayton WR, Allen CE. 1987. Evaluation of molecular interactions in myosin, fibrinogen, and myosin-fibrinogen gels. J. Agric Food Chem. 35(4):559-563.

Fojtik TR. 1997. Utilization of modified pork skin in fresh sausage [MS thesis]. University of Nebraska-Lincoln, Lincoln, NE.

Foster JA, Shapiro R, Voynow P, crombie G, Faris B, Franzblau C. 1975. Isolation of soluble elastin from lathyritic chicks: Comparison to tropoelastin from copper deficient pigs. Biochem. 14:5343.

Franzblau C. 1971. Elastin. In: Florkin M, Stoltz EH, editors. Comprehensive Biochemistry. Amsterdam: Elsevier Appl. Sci. 26:659-712.

Garrett RH, Grisham CM. 1999. Biochemistry 2nd ed. Saunders College Pub. United States of America.

Gillet TA. 1987a. Adipose and connective tissue. In: Pearson AM, Dutson TR, editors. Advances in Meat Research, Restructured Meat and Poultry Products. New York, NY: Avi Publishing Co. 3:73-124.

Gillet TA. 1987b. Gelatin gels. In: Pearson AM, Dutson TR, Bailey AJ, editors. Advances in Meat Research, Collagen as a Food. New York, NY: Avi Publishing Co. 4:223-249.

Gillet TA. 1987c. Collagen in meat emulsions. In: Pearson AM, Dutson TR, Bailey AJ, editors. Advances in Meat Research, Collagen as a Food. New York, NY: Van Nostrand Reinhold Company. 4:223-249.

Glanville RW, Kuhn K. 1979. The primary structure of collagen. In: Parry DA, Creamer LK, editors. Fibrous Proteins: Scientific, Industrial and Medical Aspects. New York, NY: Acedemic Press Inc. 1:133-150.

Gonzalez GM. 1998. Effect of milk protein on the properties of light chicken bologna [MS thesis]. Iowa State University, Ames, IA.

Greaser ML. 1991. An overview of the muscle cell cytoskeleton. Proc. Recip. Meat Conf. National Live Stock and Meat Board, Chicago, IL. 44:1-5.

Guzmań JC, McMillin KW, Bidner, TD, Dugas-Sims S, Godber JS. 1995. Texture, color and sensory characteristics of ground beef patties containing bovine blood proteins. J Food Sci. 60(4):657-660.

Harper GS. 1999. Trends in skeletal biology and the understanding of toughness in beef. Aust. J. Agric. Res. 50:1105-1129.

Hamm R. 1971. Interactions between phosphates and meat proteins. In: Mann JM, Melnychyn P, editors. Symposium: Phosphates in Food Processing. Westport, CT: AVI Publishing Co. P 65-82.

Hamann DD. 1988. Rheology as a means of evaluating muscle functionality of processed foods. Food Technol. 42(6):66-71.

Hamann DD, Webb NB. 1979. Sensory and instrumental evaluation of material properties of fish gels. J. Texture Stud. 10(2):117-130.

Hedrick HB, Aberle ED, Forrest JC, Gerrard DE, Mills EW. 1994. Principles of Meat Science 3rd ed. Dubuque, IA: Kendall/Hunt Pub. Co.

Henrickson RL. 1980. Hide collagen as food. Symposium. New uses of untanned hide collagen. American Leather Chemist Assn. Conv. JALCA 75:464. Cited by Chavez J, Henrick RL, Rao BR. 1986. Collagen as a hamburger extender. J. Food Quality. 8(4):265-272.

Hermansson AM. 1978. Physico-chemical aspects of soy proteins structure formation. J. Texture Stud. 9(1):33-58.

Hermansson AM. 1979. Aggregation and denaturation involved in gel formation. In: Pour-El A., editor. Functionality and Protein Structure. Washington, DC: American Chemical Society. P 82-103.

Hill F. 1966. The solubility of intramuscular collagen in meat animals of various ages. J. Food Sci. 31:161-166.

Hollingsworth CA. 1981. The effect of processing parameters on bacon characteristics. M.S. Thesis. University of Nebraska-Lincoln.

Hoogenkamp HW. 1998. Transforming soybeans into functional food ingredients. In: Vegetable Proteins: Interactive Technology and Marketing for Meat, Poultry and Lifestyle Foods. St. Louis, MO. Protein Technologies International. P 23-30.

Hoogenkamp HW. 2001. Functional non-meat protein properties. In: Soy Protein and Meat Formulations. St. Louis, MO. Protein Technologies International. P 75-87.

Hudspeth JP, May KN. 1969. Emulsifying capacity of salt-soluble proteins of turkey meat. II. Heart, gizzard and skin from broilers, turkeys, hens, and ducks. Food Technol. 23(3):99-100.

Jobling A. 1984. New applications for collagenous proteins in meat products. J. Sci. Food Agric. 35(11):1264-1265.

Jones KW. 1984. Collagen properties in processed meats. Proceedings of the Meat Industry Research Conference, American Meat Science Association, American Meat Institute, Chicago, Ill. P 18-28.

Jones KW, Mandigo RW. 1982. Effects of chopping temperature on the microstructure of meat emulsions. J. Food Sci. 47(6):1930-1935.

Jones KW, Snyder WD, Mandigo RW, Calkins CR. 1982. Effects of varying collagen levels on the emulsion properties of sausage batters [abstract]. In: Annual Meeting of the American Society of Animal Science. Guelph, Canada. Abstract nr 307.

Judge MD, Aberle ED. 1982. Effects of chronological age and postmortem aging on thermal shrinkage temperature of bovine intramuscular collagen. J. Anim. Sci. 54:68-71.

Kijowski J. 1993. Thermal transition temperature of connective tissues from marinated spent hen drumsticks. Inter. J. Food Sci. Technol. 28(6):587-594.

Kijowski J. 2001. Muscle proteins. In: Zdzislaw E, Sikorski editors. Chemical and Functional Properties of Food Proteins. Lancaster, PA: Technomic Pub. Co. Inc. P 233-270.

Kinsella JE. 1976. Functional properties of proteins in foods: A survey. CRC Crit. Rev. Food Sci. Nutri. 7(3):219-280.

Knipe CL. 1988. Production and use of animal blood and blood proteins for human food. In: Pearson AM, Dutson TR, editors. Edible Meat By-products Advances in Meat Research. Essex, England: Elsevier Science Publishers LTD. 5:147-165

Kolakowski E. 2001. Protein determination and analysis in food systems. In: Zdzislaw E, Sikorski, editors. Chemical and Functional Properties of Food Proteins. Lancaster, PA: Technomic Pub. Co. Inc. P 57-112.

Kramlich WE, Pearson AM, Tauber FW. 1973. Processed Meats. The AVI Publishing Company, Inc. Westport, CT.

Ladwig KM, Knipe CL, Sebranek JG. 1989. Effects of collagen and alkaline phosphate on time of chopping, emulsion stability and protein solubility of finely cut meat systems. J. Food Sci. 54(3):541-544.

Lamkey JW. 1998. Non-meat ingredients for meat processing. Proc. Recip. Meat Conf. National Live Stock and Meat Board, Chicago, IL. 51:48-52.

Lauck RM. 1975. The functionality of binders in meat emulsions. J. Food Sci. 40(4):736-740.

Li-Chan E, Nakai S, Wood DF. 1984. Hydrophobicity and solubility of meat proteins and their relationship to emulsifying properties. J. Food Sci. 49(2):345-350.

Li-Chan E, Nakai S, Wood DF. 1985. Relationship between functional (fat binding, emulsifying) and physicochemical properties of muscle proteins. Effects of heating, freezing, pH and species. J. Food Sci. 50(4):1034-1040.

Mandigo RW, Eilert SJ. 1994. Strategies for reduced-fat processed meats. In: Hafs HD, Zimbelman editors. Low-fat Meats: Design Strategies and Human Implications. New York, NY: Academic Press, Inc. P 145-166.

Maurer AJ, Baker RC. 1966. The relationship between collagen content and emulsifying capacity of poultry meat. Poultry Sci. 45(6):1317-1321.

McClain PE. 1976. Chemistry of collagen crosslinks. Proc. Recip. Meat Conf. National Live Stock and Meat Board, Chicago, IL. 29:350-374.

McCord A, Smyth AB, O'Neill EE. 1998. Heat-induced gelation properties of salt-soluble muscle proteins as affected by non-meat proteins. J. Food Sci. 63(4):580-583.

McCormick RJ. 1989. Influence of nutrition on collagen metabolism and stability. Proc. Recip. Meat Conf. National Live Stock and Meat Board, Chicago, IL. 42:137-148.

McKechnie R. 1983. Oat products in bakery foods. Cereal Foods World. 28:635-637.

Miller A. 1976. The structure of collagen. In: Markham R, Horne RW, editors. Structure-function Relationships of Proteins. Amsterdam, NY: North-Holland Publishing Co. P 59-70.

Monagle CW, Toledo RT, Saffle RL. 1974. Effect of smokehouse temperature, humidity and air velocity on rate of heating and quality of frankfurters. J. Food Sci. 39(3):602-604.

Montejano JG, Hamann DD, Lanier TC. 1985. Comparison of two instrumental methods with sensory texture of protein gels. J. Texture Stud. 16(4):403-424.

Mulvhill D, Kinsella J. 1987. Gelatin characteristics of whey proteins and β-lactoglobulin. Food Technol. 41(9):102-111.

Müller WD, Wagner B. 1985. Processing collagen tissue into frankfurter-type sausage products. Fleischwirthsch. 65(9):1098.

Murmann D, Wenzel S. 1986. The effect of blood plasma concentrate on the quality of frankfurter-type sausage. Fleischwirtsch. 66(7):1132.

Naghski J, Feairheller SH. 1987. Meat animal byproducts and their utilization: hides and skins. In: Price JF, Schweigert BS, editors. The Science of Meat and Meat Proteins 3rd ed. Westport, CT: Food and Nutrition Press, Inc. P 545-556.

Nunes K. 1999. Building a better burger? Meat & Poultry. Oct:74-82.

Ockerman HW, Hansen CL. 1988. Animal by-product processing. Ellis Horwood Ltd., Chister, England and VCH Verlassgesellschaft mbH, New York, NY.

Osburn WN, Mandigo RW. 1998. Reduced-fat bologna manufactured with poultry skin connective tissue gel. Poultry Sci. 77(10):1574-1584.

Osburn WN, Mandigo RW, Calkins CR. 1999. Utilization of desinewed beef connective tissue gel in reduced-fat bologna. J. Muscle Foods. 10(1):29-50.

Osburn WN, Manidgo RW, Eskridge KM. 1997. Pork skin connective tissue gel utilization in reduced-fat bologna. J. Food Sci. 62(16):1176-1182.

Pantana-Anake C, Foegeding EA. 1985. Rheological and stability transitions in meat batters containing soy protein concentrate and vital wheat gluten. J. Food Sci. 50(1):160-164.

Paulson AT, Tung MA, Garland MR, Nakai S. 1984. Functionality of modified plant proteins in model food systems. Can. Inst. Food Sci. Technol. J. 17(4):202-208.

Payne, CA. 1993. The use of starch in meat products [Ph.D. dissertation]. Kansas State University, Manhattan, KS.

Pearson AM, Dutson TR, Bailey AJ, editors. 1987. Advances in Meat Research. New York, NY: Van Nostrand Reinhold. 4:396-.

Pearson AM, Tauber FW. 1984. Processed Meats 2nd ed. New York, NY: Van Nostrand Reinhold Company Inc.

Pearson AM, Young RB. 1989. The connective tissues: Collagen, elastin, and ground substances. In: Muscle and Meat Biochemistry. San Diego, CA: Academic Press, Inc. P 338-385.

Piez KA. 1967. Ch. 5. Soluble collagen and the components resulting from its denaturation. In: Ramachandran GN, eiditor. Chemistry of Collagen. New York, NY: Acedemic Press Inc. P 207-248.

Porteous JD. 1981. The collagen content of various sausage meats. Can. Inst. Food Sci. Technol. J. 14(3):224-226.

Prabhu GR. 2003. Poultry collagen: Ingredients that combine flavor and functionality. Meat and Poultry. January: 68-75.

Prabhu GR, Doerscher DR. 2000. Collagen's new application. Meat and Poultry. April: 65-69.

Pritchard PE, Brock CJ. 1994. The glutenin fraction of wheat protein: the importance of genetic background on its quantity and quality. J. Sci. Food Agric. 65: 401-406.

Puolanne E, Ruusunen M. 1981. The properties of connective tissue membrane and pig skin as raw materials for cooked sausage. Meat Sci. 5(5):371-382.

Purslow PP. 1985. The fracture properties and thermal analysis of collageneous tissues. Presented at the Collagen as a Food Symposium, Nov. 9-13. Michigan State University, East Lansing, MI.

Quint LN, Mandigo RW, Calkins CR. 1987. Use of pork skin pre-emulsions in a low-fat pork loaf product. Nebraska Swine Report. EC 87-219:22-24. Univ. of Nebraska, Lincoln, NE.

Randall CJ, Raymond DP, Voisey PW. 1976. Effect of various animal and vegetable protein materials on replacing the beef component in a meat emulsion system. Can. Inst. Food Sci. Technol. J. 9(4):216-221.

Rao BR, Henrickson RL. 1983. Food grade hide collagen in bologna effect on functional properties, texture and color. J. Food Qual. 6(1):1-10.

Romans JR, Jones KW, Costello WJ, Carlson CW, Ziegler PT. 1985. The Meat We Eat. 12th ed. Danville, IL: The Interstate Printers and Publishers, Inc.

Rongey EH. 1965. A simple objective test for sausage emulsion quality. Proc of Meat Ind. Res. Conf. American Meat Institute Foundation, Chicago, IL.

Ross R. 1971. The smooth muscle cell. II. Growth of smooth muscle in culture and formation of elastic fibers. J. Cell Biol. 50:172-179.

Ross R, Fialkow PJ, Altman LK. 1977. The morphogenesis of elastic fibers. Adv. Exp. Med. Biol. 79:7.

Rust RE. 1987. Sausage products. In: Price JF, Schweigert BS, editors. The Science of Meat and Meat Products, 3rd ed. Westport CT: Food and Nutrition Press, Inc. P 473-485.

Sadler DHN, Young OA. 1993. The effect of preheated tendon as a lean meat replacement on the properties of fine emulsion sausage. Meat Sci. 35(2): 259-268.

Sadowska M. 1987. The effect of collagen on the stability and rheological properties of cooked sausages. In: Proc. European Meeting of Meat Research Workers, Helsinki, Finland. 2:274-276.

Sadowska M, Sikorski AE, Dobosz M. 1980. The influence of collagen on the rheological properties of meat homogenates. Lebensm. -Wiss. u. -Technol. 13(5):232-236.

Saffle RL, Carpenter JA, Moore DG. 1964. Peeling ease of frankfurters. 1. Effect of chemical composition, heat, collagen, and type of fat. Food Technol. 18(12):130-132.

Samejima K, Ishioroshi M, Yasui T. 1981. Relative roles of the head and tail portions of the molecule in heat induced gelation of myosin. J. Food Sci. 46(5):1412-1418.

Sanes JR, Cheney JM. 1982. Lamin, fibronectin, and collagen in synaptic and extrasynaptic portions of muscle fiber basement membrane. J. Cell Biol. 93: 442-451.

Satterlee LD, Zachariah NY, Levin E. 1973. Utilization of beef and pork skin hydrolzates as a binder or extender in sausage emulsions. J. Food Sci. 38(2):268-270.

Scheraga HA. 1961. Protein Structure. New York, NY: Academic Press. P 81.

Schmidt RH. 1981. Gelation and coagulation. In: Cherry JP, editor. Protein Functionality in Foods. Washington DC: Am. Chem. Soc. P 131.

Schmitt FO, Gross J, Highberger JH. 1955. Tropocollagen and the properties of fibrous collagen. Exp. Cell Res. Suppl. 3:326.

Schut J. 1976. Meat emulsions. In: Friberg S, editor. Food Emulsions. New York, NY: Marcel Dekkar Inc. P 386-458.

Scott-Blair GW. 1969. Elementary Rheology. New York, NY: Academic Press.

Siegel DG, Church KE, Schmidt GR. 1979. Gel structure of non-meat proteins as related to their ability to bind meat pieces. J. Food Sci. 44:1276-1279.

Smith DM, Rose AJ. 1995. Properties of chicken salt-solubl protein and whey protein concentrate gels as influenced by sodium tripolyphosphate. Poultry Sci. 74(1):169-175.

Steenblock RL. 1999. The effects of oat fiber on the properties of light bologna and fat-free frankfurters. [MS thesis] Iowa State University, Ames, IA.

Steffe JF. 1996. Rheological Methods in Food Process Engineering. East Lansing, MI: Freeman Press. P 1-91.

Su YK, Bowers JA, Zayaz JF. 2000. Physical characteristics and microstructure of reduced-fat frankfurters as affected by salt and emulsified fats stabilize with nonmeat proteins. J. Food Sci. 65(1):123-128.

Swift CE, Ellis R. 1956. The action of phosphates in sausage products: Factors affecting water retention of phosphates treated ground meat. Food Technol. 10(11):546-552.

Szczesniak AS. 1963. Objective measurements of food texture. J. Food Sci. 28(4):410-420.

Szczesniak AS, Brandt MA, Friedman HH. 1963. Development of standard rating scales for mechanical parameters of texture and correlation between the objective and sensory methods of texture evaluation. J. Food Sci. 28(4):397-403.

Townsend WE, Olson DG. 1987. Cured meats and cured meat processing. In: The Science of Meat and Meat Products, 3rd ed., Price, JF and Schweigart BS., 431-456. Food and Nutrition Press, Inc. Westport, CT.

Townsend WE, Witnauer LP, Riloff JA, Swift CE. 1968. Comminuted meat emulsions: Differential thermal analysis of fat transitions. Food Technol. 22(3):71-90.

Ukabam IO. 1998. Raw material utilization: A global perspective. Proc. Recip. Meat Conf. National Live Stock and Meat Board, Chicago, IL. 51:44-47.

United States Department of Agriculture. 1988. Food standards and labeling policy book. Food Safety and Inspection Service, United States Department of Agriculture. Washington, DC.

United States Department of Agriculture. 1995. Processing inspectors' calculations handbook. FSIS Directive 7620.3 (http://www.fsis.usda.gov). Food Safety and Inspection Service, United States Department of Agriculture. Washington, DC.

United States Department of Agriculture. 2002a. Code of Federal Regulations. Citation 9CFR319.15b (http://www.usda.gov). United States Department of Agriculture. Washington, DC.

United States Department of Agriculture. 2002b. Saving of blood from livestock as an edible product. Code of Federal Regulations. Citation 9CFR310.20 (http://www.usda.gov). United States Department of Agriculture. Washington, DC.

Vittayanont M, Vega-Warner V, Steffe JF, Smith DM. 2001. Heat-induced gelation of chicken pectoralis major myosin and β-lactoglobulin. J. Agric. Food Chem. 49(3):1587-1594.

Wang SF, Smith DM. 1994. Heat-induced denaturation and rheological properties of chicken breast myosin and F-actin in the presence and absence of pyrophosphate. J. Agric. Food Chem. 42(12):2665-2670.

Wang SF, Smith DM, Steffe JF. 1990. Effect of pH on the dynamic rheological properties of chicken breast salt-soluble proteins during heat-induced gelation. Poultry Sci. 69(12):2220-2227.

Weiss JB, Ayad S. 1982. An introduction to collagen. In: Weiss JB, Jayson MIV, editors. Collagen in Health and Disease. New York, NY: Churchill Livingstone. P 1-17.

Whiting RC. 1989. Contributions of collagen to the properties of comminuted and restructured meat products. Proc. Recip. Meat Conf. National Live Stock and Meat Board, Chicago, IL. 42:149-155.

Wiley EL, Reagan JO, Carpenter JA, Campion DR. 1979. Connective tissue profiles of various raw sausage materials. J. Food Sci. 44(3):918-921.

Wismer-Pedersen J. 1979. Utilization of animal blood in meat products. Food Technol. August:75-80.

www.ibiblio.org. 2003. The Public's Library and Digital Archive.

Xiong YL. 1994. Myofibrillar protein form different fiber types: Implications of biochemical and functional properties in meat processing. Crit. Rev. Food Sci Nutri. 34(3):293-320.

Yasui T, Ishioroshi M, Nakano H, Samejima K. 1979. Changes in shear modulus, ultrastructure and spin relaxation times of water associated with heat-induced gelationof myosin. J. Food Sci. 44(4):1201-1204, 1211.

Ziegler GR, Acton JC. 1984. Mechanisms of gel formation by proteins of muscle tissue. Food Technol. 38(5):77-80, 82.

CHAPTER 3. PRELIMINARY RESERCH CONDUCTED TO DETERMINE THE EFFECT OF BEEF PLASMA AND COLLAGENS IN A MODEL EMULSION SYSTEM

Abstract

A model meat emulsion system was developed to study emulsions formulated with a portion of lean replaced by various protein ingredients. The emulsion consisted of the basic ingredients of lean meat, fat, salt, ice/water, and the treatment ingredient. A portion of the lean was replaced with gelling plasma or various collagens and water. Cooked emulsion characteristics (that is pH, yield, water separation, fat separation, proximate composition, and texture characteristics) were measured. The objective of this preliminary study in a model emulsion system was to record base line data for further studies. A majority of the treatments were not significantly different ($P>0.05$) from the control, but were significantly higher ($P<0.05$) higher than the negative control for the specific treatments. The proximate composition of all treatments were not significantly different ($P>0.05$) from the control (no lean meat replacement), while some treatments displayed differences ($P<0.05$) when compared to the negative control. The negative control for 4 percent and 8 percent lean meat replacement consisted of replacing 4 percent and 8 percent of the lean meat with water in the formulation, respectively. A puncture test resulted in no significant ($P>0.05$) differences within peak force and internal force between all treatments and the control as well as the negative control for the respective treatments. Overall, most treatments were not significantly ($P>0.05$) different in texture (cohesiveness, chewiness, springiness, and hardness) when compared to the control. Significant ($P<0.05$) differences in texture did occur within some treatments compared to the negative control for the respective treatments.

Keywords: Model System, Meat Replacement, Protein Ingredients

Introduction

Currently, the United States Department of Agriculture (USDA 2002) has the standards of identity or composition of frankfurters outlined in Title 9, Chapter III, Part 319, Section 319.180a of the Code of Federal Regulations. The definition states that "frankfurters must be prepared from one or more kinds of raw skeletal muscle meat, seasoned and cured. The frankfurters may or may not be smoked and the finished product shall not contain more than 30 percent fat. Water and/or ice may be used to facilitate chopping/mixing or to dissolve the curing ingredients. The frankfurter shall not contain more than 40 percent of a combination of fat and added water."

Meat-like ingredients prefabricated from protein sources (for example vegetable proteins and so forth) continue to increase in cost. Therefore, it has been desirable to research the potential for making edible meat products from the substantial amounts of animal proteins (that is animal skin) which are currently under-utilized. As world population and consumption of food products increases, the use of alternative protein sources (for example collagens, plasmas, and so forth) are being explored in an attempt to replace a portion of the lean meat utilized in the production of processed meat products. Collagen is present in comminuted meats and meat products either as a natural component of the connective tissue of the meat used in the process or as an additive. Many processors may replace a portion of the lean with water to alleviate the cost of production. Final product characteristics such as flavor, texture, mouth-feel, and juiciness cannot be surrendered at the cost of reducing the skeletal tissue amount in processed meat products.

In processed meat production, connective tissue and collagen from a variety of sources (for example bovine hide, pork skin, natural occurring connective tissue in muscle, tendons, etc.) has been utilized in low-fat meat product formulations, extended meat product formulations, and lean meat replacement formulations. The utilization of collagen in comminuted meat systems is dependent on the formation of undesirable characteristics that may occur due to the amount of collagen in the formulation. Defects such as poor peelability, unstable batters, gel-pocket formation, and wrinkling of the outer skin have been associated with sausage products containing large quantities of high collagen (Saffle and others 1964). Collagen and connective tissue play an important role in comminuted meat products by altering product yield, texture, and stability (Jones 1984).

The majority of research conducted using connective tissue/collagen has been performed in finely comminuted meat systems. The sources of connective tissue/collagen used in research are quite numerous: beef tripe (Randall an others 1976; Jones and others 1982); tendon from beef hind leg muscles (Sadler and Young 1993); desinewed cow meat (Ladwig and others 1989); desinewed shank muscles from beef carcasses (Eilert and Mandigo 1993; Eilert and others 1996ab; Calhoun and others 1996ab; Osburn and others 1999); desinewed connective tissues from pork (Delmore and Mandigo 1994); beef skin (Satterlee and others 1973; Asghar and Henrickson 1982; Rao and Henrickson 1983, Chavez and others 1985); pork skin (Satterlee and others 1973; Sadowska and others 1980; Puolanne and Ruusunen 1981; Quint and others 1987; Delmore and Mandigo 1994; Fojtik 1997; Osburn and others 1997); poultry skin (Osburn and Mandigo 1998); turkey skin (Acton and Dick 1978); and meats containing high amounts of connective tissue (Maurer and Baker 1966; Carpenter and others 1979; Ambrosiadis and Wirth 1984).

Research on protein interaction has also been conducted by numerous authors in meat processing model systems (Townsend and others 1968; Lauck 1975; Jones and Mandigo 1982; Paulson and others 1984; Patana-Anake and Foegeding 1985; Su and others 2000).

Townsend and others (1968) developed a "bench top" method to evaluate emulsion stability of basic sausage formulations. Although these processing conditions may introduce slight variation from the meat ingredient utilized, a better applied representation of the protein interaction is revealed that will occur in the commercial product. It is of importance to minimize the pH and muscle variation of the raw meat ingredient, as well as the moisture, fat, protein, and salt of the meat batter produced.

The objective of this preliminary study in a model emulsion system was to record base line data for further studies. The emulsion consisted of the basic ingredients of lean meat, fat, salt, ice/water, and the treatment ingredient.

Materials and Methods

Preparing the Meat Block

The lean pork source (ham *semimembranosus*) was sorted on a subjective color measurement by Swift and Company personnel (Marshalltown, IA), using the National Pork Producers Council color standards (1999), in an attempt to decrease variability in the raw materials used with this phase of the project. The lean pork was trimmed practically free of all visible fat, vacuum packaged in 1.8-2.3 kgs bags, and shipped fresh to the Iowa State University Meat Laboratory. The lean pork was subsequently frozen in the blast freezer (-34 °C/-30 °F) and moved the next day into another freezer (-28 °C).

Prior to processing, the lean pork was tempered in a cooler (2 °C) for initial grinding. The temperature of the lean pork was -1 °C prior to grinding. All visible fat was removed

and the ham was cut into sections to fit into the grinder. The lean was crust frozen in the blast freezer to aid in the grinding process and maintain the temperature at -1 °C.

The lean pork was ground (Biro grinder, Model 822, Marblehead, OH) through a 0.9525 cm grinder plate. A 5.90 kg sample was taken to determine the exact lean and fat content using an Anyl Ray Fat Analyzer (Kartrig Pak, Model 316-48, Davenport, IA). The lean was then batched into individual treatments according to the required weight, packaged in vacuum bags (B540 17.8 x 30.5 cm, Cryovac Division, W.R. Grace & Co., Duncan, SC), and sealed (with vacuum) using a Multivac double chamber packaging machine (Model AG800, Kansas City, MO). Packaging film had an O_2 transmission rate of 3-6 cc/m^2/24 hr at 1 atm, 4.4 °C, and 0% relative humidity, and a vapor transmission rate of 0.5-0.6 g/645 cm^2/24hr and 100% relative humidity. The meat was then placed into the cooler (0 °C) until further processing the next day.

Preparing the Pork Fat

The source of the pork fat was pork backfat and was obtained from the Iowa State University Meat Laboratory. The pork fat was tempered in a cooler before processing. The pork fat was inspected, trimmed free of any visible lean, cut into strips and crust frozen before initial grinding to ensure the temperature was at -1 °C. The pork fat was ground through a 0.9525 cm plate. A 5.90 kg sample was taken to determine the exact lean and fat content using an Anyl Ray Fat Analyzer. The pork fat was then ground through a 0.3175 cm grinder plate. The pork fat was batched into the required weight increments for each treatment, placed on a metal tray, and put into the cooler (0 °C) for further processing.

Developing the Model System Base Formulations

The meat block formulation was set at 32.5 percent fat content to establish a target fat content of 27.5 percent in the finished product. The formulations (Table 3.1) for the

model system consisted of lean pork (ham *semimembranosus*), pork fat (pork backfat), ice, water, salt, and the treatment ingredient. The salt percentage varied between treatments to maintain a constant salt concentration based on the meat block weight.

Making the Emulsion

One day prior to processing, a bucket of ice water was placed in the cooler to equilibrate to approximately 0.5 °C. Model emulsions were produced using methods developed by Townsend and others (1968). The lean pork was chopped (Stephan chopper, Model 718.270.03, Stephan Food Processing Technology, Columbus, OH) with the salt and half of the ice/water (and treatment addition with the appropriate amount of water per treatment, if required) with a vacuum at 2100 rpm until 3 °C was achieved. The sides of the chopper bowl were scraped randomly with a plastic scraper attached internally to the chopper. The initial temperature and final temperature were measured by an internal temperature probe in the chopper. The initial temperature, final temperature, and total time required to achieve initial chop temperature were recorded.

After initial temperature was reached, the chopper was turned off, the chopper lid was removed, and the sides of the bowl were scraped with a rubber spatula. The fat and the rest of the ice/water were added and chopped under vacuum until the temperature reached 14 °C. The initial temperature, final temperature, and total time were recorded. The thermometer probe was disconnected from the chopping bowl and the thermometer probe connection was covered with a plastic cap. A scraper was used to remove any extra meat on the sides of the bowl that was not chopped with the emulsion. The emulsion was removed from the chopping bowl and placed into a labeled vacuum bag (Cryovac B540). The emulsion was then vacuum packaged (with vacuum) and placed in the cooler for approximately 6 hours until stuffed.

Procedures between the Treatments

The chopping bowl was rinsed with warm water and then ice was placed in the bowl to decrease the temperature of the bowl while rinsing the other equipment. The rubber spatula, plastic scraper, and blades were also rinsed with warm water. The ice was removed from the chopping bowl and the chopping bowl was wiped dry with paper towels. The Stephan chopper was assembled and the thermometer cable was connected to the bowl.

Stuffing the Emulsion

The vacuum bag with the emulsion was placed into the stuffer (5 lb. Sausage Stuffer, The Sausage Maker, Buffalo, NY), the tip of the bag was pulled out and cut off with scissors.

50 ml Centrifuge Tubes

The centrifuge tubes were labeled, weighed, and recorded previously. The stuffing horn (3.175 cm) was then tightened onto the stuffer. Ten 50 ml centrifuge tubes were stuffed with approximately 40-45 grams of emulsion for each treatment. The centrifuge tubes were tapped on the table to compact the emulsion in the centrifuge tube and the weight was recorded (excluding the centrifuge cap). The centrifuge tubes were sealed with a plastic cap, placed in a rack, and placed into the cooler until enough samples were accumulated to thermal process.

Wierbicki Tubes

To determine emulsion stability, the Rongey method (Rongey 1965; Sebranek and others 2001) was used. The 3.175 cm stuffing horn was also used for stuffing the Wierbicki tubes. Two Wierbicki tubes were labeled, weighed, recorded, and stuffed with approximately 25 grams of emulsion for each treatment. The emulsion was stuffed by

resting the stuffing horn on the glass disc and simultaneously turning the stuffer handle. Some pressure was applied on the emulsion so that it filled the tube without air pockets, while not forcing the emulsion past the glass disc. The Wierbicki tubes were reweighed to determine the actual sample weight. After stuffing, the Wierbicki tubes were placed into the cooler until eight Wierbicki tubes were accumulated for thermal processing.

Cellulose Casings

The stuffing horn (1.75 cm) was then tightened on the stuffer. To determine the effect of skin formation, the remaining emulsion was stuffed into a 21-22 mm cellulose casing (Devro-Teepak Wienie-Pak RP 24/10, Westchester, IL), intermediately linking the casing by hand and tying with string to hold the link in place. The treatments were labeled and weighed. The treatments were then randomly placed on a smoke stick, hung on a smokehouse truck, and placed into the cooler until all treatments were completed. Between each treatment the stuffer was disassembled and rinsed with warm water.

Thermal Processing of the Emulsion

50 ml Centrifuge Tubes

The centrifuge tubes were thermal processed in a hot water bath (72 °C) for 30 minutes to achieve an internal temperature of 71 °C. Samples were then removed from the hot water bath. The water and aqueous fat were drained from the tubes and the cooked samples were rolled over a paper towel to remove any excess liquid. The cooked sample weight was recorded and the sample was placed back into the centrifuge tube. The yield of the samples was determined using the following equation:

Percent yield = (cooked sample weight / raw sample weight) x 100

The centrifuge tubes were then sealed with the plastic cap and placed into the cooler for further analysis.

Wierbicki Tubes

The Wierbicki tubes were thermal processed in a hot water bath (72 °C) for 30 minutes to achieve an internal temperature of 71 °C. The tubes were then removed from the hot water bath and allowed to cool for 2-3 minutes. The tubes were then centrifuged at low speed (10,000 rpm) for 5 minutes. The tubes were removed from the centrifuge machine (Model 61, Chicago Surgical and Electrical Co., Chicago, IL) and the amounts of separated fat (top layer) and separated water (bottom layer) were read and recorded. The percent water separation and percent fat separation were determined by the following equations:

Percent water separation = (ml of water / sample weight) x 100

Percent fat separation = (ml of fat / sample weight) x 100

Percent total liquid separation = % water separation + % fat separation

Cellulose Casings

Thermal processing of the cellulose casing samples (frankfurter samples) was done using an Alkar thermal processing unit (Model MT EVD RSE 4, Alkar Engineering Corp., Lodi, WI). No smoke (liquid or natural) was used on any of the treatments. The final internal temperature of the product was brought to 71 °C using the cooking schedule in Table 3.2.

The treatments were weighed to determine the hot processing yield of each treatment using the following equation:

Percent hot yield = (hot cooked weight / raw weight) x 100

The treatments were then hand peeled and placed in plastic bags (Poly bags, 20.3 x 10.2 x 45.7 cm) before the samples were cooled.

Texture Analysis

Puncture Test

The puncture test was selected because the results could be directly compared even though the samples may have slightly different diameters. Texture was determined using the TA.XT2i Texture Analyzer (Texture Technologies Corp., Scarsdale, NY). Sample identification numbers were entered into the computer and a 3 mm diameter stainless steel puncture probe (TA-52) was used.

The 3 mm probe was programmed to penetrate 12 mm into each sample after the TA.XT2i detects the sample's surface at 12 grams of resistance. The penetration was 1.5 mm/second. The pre-test speed was 3.0 mm/second and the post-test speed was 10.0 mm/second. Samples were tested at room temperature (one hour after being removed from refrigeration) to ensure consistency between treatments. No tests were conducted within the last 1.27 cm of the end of the sample.

Samples were measured for penetration peak force and average interior firmness. The peak force was determined to be the force required to break the outer surface or skin (exterior firmness) of the sample. The average interior firmness was the force required to penetrate each sample between 6.0 mm and 10.0 mm peak force of penetration.

Two types of macro analysis were performed depending on which sample was analyzed. To record values that were more representative of the sample used, a macro was used for skin-on samples and a different macro was used for the tube samples and skin-off samples.

Three types of samples were analyzed using the puncture test: (1) 50 ml centrifuge tube samples, (2) cellulose casing samples with the skin on – frankfurter-skin on, (3) cellulose casing samples with the skin off – frankfurter-skin off. For the samples that are

skin off, the skin was carefully removed from the sample. For each treatment, three readings were taken per samples and two samples were measured giving a total of six measurements per treatment.

Two-Compression Test

The TA.XT2i Texture Analyzer was also used to determine the texture profile analysis of samples by a two-compression test illustrated by Bourne (1978) and Steffe (1996). The sample was cut to yield a 2.54 cm cylinder. The TA.XT2i Texture Analyzer was calibrated with a 5 kg weight and Texture Expert software was used. The test was performed at 3.3 mm per second with a 12.7 mm compression (50 percent) on one sample and a 18 mm compression (72%) on a second sample. Two compression quantities (50% and 72%) were used. A 5 gm change in force was set to signal that the sample was present. A TA-4 (40 mm cylinder) was used and the computer was set to acquire 200 points per second during the experiment.

Samples were measured for cohesiveness, gumminess, chewiness, springiness, hardness 1 (first bite), and hardness 2 (second bite). Four types of samples were analyzed using the compression test: (1) 50 ml centrifuge tube samples, (2) core samples from the 50 ml centrifuge tube, (3) cellulose casing samples with the skin on – frankfurter-skin on, and (4) cellulose casing samples with the skin off – frankfurter-skin off. For the samples that are skin off, the skin was carefully removed from the sample. One reading was taken per sample and the experiment was conducted in triplicate.

pH Determination

pH was measured on each treatment. Raw emulsion and cooked pH were measured using a pH-STAR Pistol (SFK Technology, Denmark). Prior to the measurement, the pH-STAR Pistol was calibrated using the technical calibration solutions of pH 4.6 and pH 7. The

calibration solutions were refrigerated as the pH was taken on refrigerated samples (2 °C). The identification number was recorded, the tip of the electrode was inserted into the sample, and the pH was recorded. The tip of the electrode was rinsed with distilled water between sample readings. For each treatment, measurements were made in duplicate.

Chemical Analysis (Fat, Moisture, and Protein)

Fat, moisture, and protein determinations were performed for each replication using the Soxhlet apparatus (hexane extraction) (AOAC 1990a), gravity oven drying (AOAC 1990b), and combustion method (AOAC 1993), respectively. For each treatment, measurements were made in duplicate. Ash was determined by adding the fat, moisture, and protein values together and subtracting the total from 100.

Experimental Design and Data Analysis

The study was a 7 (treatments) x 2 (treatment level) factorial design with three replications. Controls consisted of a positive control, a negative control for 1 percent treatments, and a negative control for 2 percent treatments. Data was subjected to analysis using the General Linear Model (SAS 2001) to evaluate the effect of treatments on processing parameters, proximate parameters, puncture parameters, and texture parameters. Least squares means was used to separate the means. Significant main effects were separated using the Bonferroni adjusted p-value method in which the original p-value was multiplied by the number of comparisons made (that is 14 comparisons within each treatment percentage group) (Rao 1998.).

Results and Discussion

Yield, Water Separation, Fat Separation, and pH

The yield results were not a true representation of what may occur if other non-meat ingredients (phosphate, spices, etc.) were used. Although a 90 percent yield is expected with the production of frankfurters, a much lower yield was achieved due to the lack of other non-meat ingredients in the formulation. Hot yield from the smoke house was not significant ($P>0.05$), but the yield difference (Table 3.3) from the centrifuge tubes was statistically significant ($P<0.05$). The range of the yield including all of the treatments was between 82.2 percent to 71.3 percent. When comparing only the 1 percent treatments, none of the treatments were significantly different ($P>0.05$) from the control with the exception of the whey protein concentrate. Moreover, all treatments had significantly higher ($P<0.05$) yields than the negative control for the 1 percent treatments. When comparing the 2 percent treatments, the Myogel Plus treatment had the highest yield (82.2 percent). With the exception of the Myogel Plus, chicken collagen, and turkey collagen; all other treatments were not significantly different ($P>0.05$) from the control. Furthermore, all treatments were significantly higher ($P<0.05$) when compared to the negative control for the 2 percent treatments.

The water separation ranged from 17.5 percent to 26.0 percent (Table 3.4). When comparing only the 1 percent treatments, the Myogel Plus treatment was significantly lower ($P<0.05$) in water separation than the control. None of the other 1 percent treatments were significantly different ($P>0.05$) from the control with the exception of the whey protein concentrate treatment. These results are consistent with the yield results. The whey protein concentrate treatment had a higher water separation when compared to the control and thus it had lowest yield when compared to the control yield. Furthermore, all

treatments had significantly lower ($P<0.05$) water separation percentages than the negative control for the 1 percent treatments with the exception of the whey protein concentrate. When comparing the 2 percent treatments, none of the treatments were significantly different ($P>0.05$) from the control with the exception of the Myogel Plus treatment. On the other hand, all treatments had significantly lower ($P<0.05$) water separation when compared to the negative control for the 2 percent treatment.

Fat separation data is also displayed in Table 3.4. None of the 1 percent treatments were significantly different ($P>0.05$) from the control. The 1 percent Myogel and gelling plasma:Myogel Plus treatments had a significantly lower ($P<0.05$) fat separation when compared to the negative control for the 1 percent treatments. None of the 2 percent treatments were significantly different ($P>0.05$) from the control, with exception of the chicken collagen and whey protein concentrate treatments. The 2 percent chicken collagen and whey protein concentrate treatments were the only 2 percent treatments that were not significantly different ($P<0.05$) from the negative control for the 2 percent treatments.

Overall, the pH of all treatments (1 and 2 percent) was not relevant due to the minimal differences. The pH values for the raw emulsion and the cooked samples may be statistically different in the 1 and 2 percent treatments, but were not practically different (Table 3.5). In general, the pH of the cooked emulsion was always higher than the raw emulsion pH.

Proximate Composition

There were only small differences in moisture, fat, protein and ash content. Within the 1 percent treatments, there were no significant differences ($P>0.05$) in moisture content between the treatments and the control with the exception of the whey protein concentrate treatment (Table 3.6). Furthermore, there were no significant differences ($P>0.05$)

between the treatments and the negative control for the 1 percent treatments. When comparing the moisture content of the 2 percent treatments, none of the treatments were significantly different ($P>0.05$) from the control.

Minimal differences were observed concerning the percentage of fat in the final product (Table 3.7). When comparing the 1 percent treatments, none of the treatments with the exception of the gelling plasma treatment, were significantly different ($P>0.05$) from the control and none of the treatments were significantly different ($P>0.05$) from the negative control for the 1 percent treatments. When comparing the fat content of the 2 percent treatments, all treatments were not significantly different ($P>0.05$) from the control. In general, the negative controls had a higher fat content than the treatments.

The percentage of protein (Table 3.8) in the final product did not have much variation between the treatments. When comparing the 1 percent treatments, none of the treatments were significantly different ($P>0.05$) from the control or the negative control for the 1 percent treatments. When comparing the protein content of the 2 percent treatments, all treatments were not significantly different ($P<0.05$) from the control. In general, all 2 percent treatments decreased in protein content when compared to the 1 percent treatments, with the exception of the chicken collagen and turkey collagen treatments. Although significant differences ($P<0.05$) did occur within the percentage of ash content of the treatments (Table 3.9), practical differences were not evident.

Puncture Analysis

Puncture analysis was performed on three types of samples: centrifuge tube samples, frankfurter-skin off samples, and frankfurter-skin on samples. The data from these samples were analyzed two ways to determine a difference in main effects (that is peak force and internal force) by each treatment within the type of sample analyzed and by

each type within the treatment. The data from the centrifuge tube samples will be discussed and the other data is available in the tables. Peak force, measured in grams, is a value that represents the amount of force that is required to break the exterior surface of the sample. Internal force, also measured in grams, is a value that represents the amount of force that is required to go through the internal surface of the sample.

Table 3.10 displays the puncture data from centrifuge tube samples by each treatment. In comparison of the 1 percent treatments, none of the treatments were significantly different ($P>0.05$) in peak force when compared to the control. With exception of the gelling plasma, none of the other treatments displayed significant differences when compared to the negative control for the 1 percent treatments. When comparing the 2 percent treatments, none of the treatments had a significantly different ($P>0.05$) peak force when compared to the control, with the exception of the Myogel Plus treatment, which was significantly lower. With the exception of the gelling plasma, none of the treatments were significantly different ($P>0.05$) in peak force when compared to the negative control for the 2 percent treatments.

None of the 1 percent treatments did displayed a significantly different ($P>0.05$) internal force from the control. Within the 2 percent treatments, with the exception of the whey protein concentrate treatment, none of treatments were significantly different ($P>0.05$) from the control and none of the treatments were significantly different from the negative control for the 2 percent treatments. In general, the 1 percent treatments displayed a higher peak force and a higher internal force when compared to the 2 percent treatments.

Further puncture data was recorded from other types of samples that were produced in this preliminary research. These data will not be discussed, but are displayed in tables:

Table 3.11	Frankfurter-skin off	Peak Force and Internal force
Table 3.12	Frankfurter-skin on	Peak Force and Internal force

As stated previously, the data from the samples were also analyzed to determine a difference in main effects (that is peak force and internal force) by each type within the treatment. The effect of sample type of peak force is displayed in Figure 3.1. The frankfurter-skin on samples were consistently higher in peak force when compared to other sample types. This pattern was due to the "skin formation" from the thermal processing schedule that was applied. Although the centrifuge samples were lower than the frankfurter-skin on samples, they were still higher in peak force when compared to the frankfurter-skin off samples.

The effect of sample type of internal force is displayed in Figure 3.2. In general, the centrifuge samples displayed a higher internal force when compared to the other types of samples analyzed. Overall, the internal force of the frankfurter-skin on samples was slightly higher than the frankfurter-skin off samples. The higher internal force of the centrifuge samples was probably due to the difference in thermal processing (that is water bath vs. smokehouse).

Texture Profile Analysis

Texture analysis was performed on four types of samples: centrifuge tube samples, centrifuge tube core samples, frankfurter-skin off samples, and frankfurter-skin on samples. The data from these samples were analyzed two ways to determine a difference in main effects (that is peak force and internal force) by each treatment within the type of sample analyzed and by each type within the treatment. The data from the centrifuge tube samples will be discussed and the other data is available in the tables. Although gumminess, and hardness 2 (second bite) were measured, the attributes of cohesiveness,

chewiness, springiness, and hardness 1 (first bite) are the main effects that pertain to the texture analysis of frankfurters.

Cohesiveness and chewiness of centrifuge tube samples are shown in Table 3.13. In comparison of the 1 percent treatments, none of the treatments were significantly the different ($P>0.05$) from the control. The Myogel Plus treatment was the only treatment that had a significantly higher ($P<0.05$) cohesiveness value when compared to the negative control for the 1 percent treatments. In comparison with the 2 percent treatments, none of the treatments were significantly different ($P>0.05$) from the control. The Myogel Plus and the gelling plasma:Myogel Plus treatments were the only treatments that displayed a significantly higher ($P<0.05$) cohesiveness value when compared to the negative control for the 2 percent treatments.

Chewiness values are also displayed in Table 3.13 for centrifuge tube samples. None of the chewiness value of the treatments (1 and 2 percent) were significantly different ($P>0.05$) from the control. At the same time, none of the 1 percent treatments, were significantly different ($P>0.05$) in chewiness values from the negative control for the 1 percent treatments. In comparison of the 2 percent treatments, the gelling plasma:Myogel Plus treatment was the only treatment that had a significantly higher ($P>0.05$) chewiness value when compared to the negative control for the 2 percent treatments.

Springiness and hardness of centrifuge tube samples are shown in Table 3.14. In comparison of the 1 percent treatments, there were no significant differences ($P<0.05$) in springiness between any of the treatments and the control and the negative control for the 1 percent treatments. In comparison of the 2 percent treatments, there were no significant differences ($P>0.05$) in springiness between any of the treatments and the control. The

gelling plasma and gelling plasma:Myogel Plus treatments had significantly higher (P>0.05) springiness values when compared to the negative control for the 2 percent treatments.

Hardness (first bite) values are also displayed in Table 3.14. In comparison of the 1 percent treatments, there were no significant differences (P>0.05) in springiness between any of the treatments and the control and the negative control for the 1 percent treatments. In the comparison of the 2 percent treatments, the chicken collagen and whey protein concentrate treatments had significantly lower (P<0.05) hardness values than the control. At the same time, none of the treatments displayed significantly different (P>0.05) hardness values when compared to the negative control for the 2 percent treatments.

Further texture data was recorded from other types of samples (e.g centrifuge tube core, frankfurter-skin off, and frankfurter-skin on) that were produced in this preliminary research. These data will not be discussed, but are displayed in tables.

Table 3.15	Centrifuge tube core	Cohesiveness and Chewiness
Table 3.16	Centrifuge tube core	Springiness and Hardness
Table 3.17	Frankfurter-skin off	Cohesiveness and Chewiness
Table 3.18	Frankfurter-skin off	Springiness and Hardness
Table 3.19	Frankfurter-skin on	Cohesiveness and Chewiness
Table 3.20	Frankfurter-skin on	Springiness and Hardness

The texture data from the samples were also analyzed to determine a difference in main effects (that is cohesiveness, chewiness, springiness, and hardness) by each type within the treatment. Overall, cohesiveness values were relatively similar. Figure 3.3 displays the effect of sample type of the cohesiveness values for the treatments. Although distinct differences are not evident, overall the frankfurter-skin on samples seem to have the highest cohesiveness of all of the sample types, while the core samples display the lowest cohesiveness values. The frankfurter skin-off and centrifuge tube core samples have

relatively similar chewiness values (Figure 3.4). Overall, the centrifuge tube samples have the highest chewiness value, followed by frankfurter-skin on samples.

The effect of sample type on springiness values are displayed in Figure 3.5. In general, the centrifuge tube samples tended to have a higher springiness value, but were not consistent over all treatments. The hardness (first bite) value of the centrifuge tube samples tended to have the highest value (Figure 3.6). The frankfurter-skin off samples were consistently lower than all other samples types across all treatments. Overall, in the descending order of hardness values, the centrifuge tube samples had the highest value followed by the core or frankfurter-skin on samples, with the frankfurter-skin off samples having the lowest hardness value. Overall, the amount (that is 1 percent vs. 2 percent) was not consistently represented over any texture characteristic or sample type researched.

Conclusions

The results of this study may be misleading due to the emulsion that was created with only the basic ingredients of lean meat, fat, salt, ice/water and the treatment ingredient and no additional binders. Although a meat batter was formed utilizing the techniques described throughout this paper, the water holding capacity was much lower than a typical, stable meat batter, which in turn affected the yield, water separation and texture parameters measured. The yield results were lower than would be expected if other non-meat ingredients (for example phosphate, spices, etc.) would have been utilized. The utilization of the other non-meat ingredients would also have beneficial effects on water and fat separation. The yield, water separation, fat separation, and proximate composition may have an effect on the final product characteristics (for example puncture and texture attributes). Therefore, the techniques and results of this preliminary research were utilized

to further investigate the use of gelling plasma and various collagens in a meat matrix that contains all standard ingredients of a meat batter (for example lean meat source, fat meat source, water/ice, salt, curing salt, phosphate, sodium erythorbate, and spices).

References

Acton JC, Dick RL. 1978. Effect of skin content on some properties of poultry meat loaves. Poultry Sci. 57(5):1255-1259.

Ambrosiadis J, Wirth F. 1984. Comminution of connective tissue and temperature pattern in the manufacture of frankfurter-type sausages. Fleischwirtschaft. 64(8):945-950.

[A.O.A.C.] Association of Official Analytical Chemists. 1990a. Fat (crude) or ether extract in meat. In: Official Methods of Analysis, 15th ed. Arlington, VA: AOAC 960.39.

[A.O.A.C.] Association of Official Analytical Chemists. 1990b. Moisture in meat. In: Official Methods of Analysis, 15th ed. Arlington, VA: AOAC 950.46.

[A.O.A.C.] Association of Official Analytical Chemists. 1993. Crude protein in meat and meat products. In: Official Methods of Analysis, 15th ed 4th suppl. Arlington, VA: AOAC 992.15.

Asghar A, Henrickson RL. 1982. Functional properties of food-grade bovine hide collagen in coarse bologna. II. Effect on different protein fractions. J. Food Quality. 5(4):271-284.

Bourne MC. 1978. Texture profile analysis. Food Technol. 32(7):62-66, 72.

Calhoun CM, Eilert SJ, Mandigo RW. 1996a. Connective tissue/acidic phosphate preblend effects on reduced fat frankfurters. J. Food Sci. 61(2):459-464.

Calhoun CM, Eilert SJ, Mandigo RW. 1996b. Characteristics of low-fat, high-added-water frankfurters manufactured with preblends of connective tissue and alkaline phosphates. J. Muscle Foods. 7(4):471-487.

Carpenter JA, Wiley EL, Reagan JO, Campion DR. 1979. Relationship of collagen content to functional properties of sausage meats. In: Carpenter JA, editor. 21st Proceeding of Meat Science Institute. P 71-74.

Chavez J, Henrick RL, Rao BR. 1985. Collagen as a hamburger extender. J. Food Quality. 8(4):265-272.

Delmore RJ, Mandigo RW. 1994. Modified pork connective tissue for use in low-fat high added water frankfurters [abstract]. In: IFT Annual Meeting Book of Abstracts; 1994 June 25-29; Atlanta, GA. Chicago, IL.: Institute of Food Technologists. Abstract nr 47D-27.

Jones KW. 1984. Collagen properties in processed meats. Proceedings of the Meat Industry Research Conference, American Meat Science Association, American Meat Institute, Chicago, Ill. P 18-28.

Jones KW, Mandigo RW. 1982. Effects of chopping temperature on the microstructure of meat emulsions. J. Food Sci. 47(6):1930-1935.

Ladwig KM, Knipe CL, Sebranek JG. 1989. Effects of collagen and alkaline phosphate on time of chopping, emulsion stability and protein solubility of finely cut meat systems. J. Food Sci. 54(3):541-544.

Lauck RM. 1975. The functionality of binders in meat emulsions. J. Food Sci. 40(4):736-740.

Eilert SJ, Calhoun CM, Mandigo RW. 1996a. Phosphate type, concentration and preblend duration to improve water holding capacity of beef connective tissue. J. Muscle Foods. 7(2):255-269.

Eilert SJ, Mandigo RW, Sumner SS. 1996b. Phosphate and modified beef connective tissue effects on reduced fat, high water-added frankfurters. J. Food Sci. 61(5):1006-1011, 1029.

Eilert SJ, Mandigo RW. 1993. Procedure for soluble collagen in thermally processed meat products, J. Food Sci. 58(5):948-949.

Fojtik TR. 1997. Utilization of modified pork skin in fresh sausage [MS thesis] University of Nebraska-Lincoln, Lincoln, NE.

Maurer AJ, Baker RC. 1966. The relationship between collagen content and emulsifying capacity of poultry meat. Poultry Sci. 45(6):1317-1321.

National Pork Producers Council 1999. Color, texture, exudation; color standards, and marbling standards. Pork Quality Standards. National Pork Board. Des Moines, IA.

Osburn WN, Mandigo RW. 1998. Reduced-fat bologna manufactured with poultry skin connective tissue gel. Poultry Sci. 77(10):1574-1584.

Osburn WN, Mandigo RW, Calkins CR. 1999. Utilization of desinewed beef connective tissue gel in reduced-fat bologna. J. Muscle Foods. 10(1):29-50.

Osburn WN, Manidgo RW, Eskridge KM. 1997. Pork skin connective tissue gel utilization in reduced-fat bologna. J. Food Sci. 62(16):1176-1182.

Pantana-Anake C, Foegeding EA. 1985. Rheological and stability transitions in meat batters containing soy protein concentrate and vital wheat gluten. J. Food Sci. 50(1):160-164.

Paulson AT, Tung MA, Garland MR, Nakai S. 1984. Functionality of modified plant proteins in model food systems. Can. Inst. Food Sci. Technol. J. 17(4):202-208.

Puolanne E, Ruusunen M. 1981. The properties of connective tissue membrane and pig skin as raw materials for cooked sausage. Meat Sci. 5(5):371-382.

Quint LN, Mandigo RW, Calkins CR. 1987. Use of pork skin pre-emulsions in a low-fat pork loaf product. Nebraska Swine Report. EC 87-219:22-24. Univ. of Nebraska, Lincoln, NE.

Randall CJ, Raymond DP, Voisey PW. 1976. Effect of various animal and vegetable protein materials on replacing the beef component in a meat emulsion system. Can. Inst. Food Sci. Technol. J. 9(4):216-221.

Rao BR, Henrickson RL. 1983. Food grade hide collagen in bologna effect on functional properties, texture and color. J. Food Qual. 6(1):1-10.

Rao PV. 1998. Single factor studies: Comparing means and determining sample sizes. In: Statistical Research Methods in the Life Sciences. Pacific Grove, CA: Brooks/Cole Publishing Co. P326-377.

Sadler DHN, Young OA. 1993. The effect of preheated tendon as a lean meat replacement on the properties of fine emulsion sausage. Meat Sci. 35(2): 259-268.

Sadowska M, Sikorski AE, Dobosz M. 1980. The influence of collagen on the rheological properties of meat homogenates. Lebensm. -Wiss. u. -Technol. 13(5):232-236.

Saffle RL, Carpenter JA, Moore DG. 1964. Peeling ease of frankfurters. 1. Effect of chemical composition, heat, collagen, and type of fat. Food Technol. 18(12):130-132.

SAS Institute, Inc. 2001. SAS user's guide, version 8.2. SAS Institute. Cary, NC.

Satterlee LD, Zachariah NY, Levin E. 1973. Utilization of beef and pork skin hydrolzates as a binder or extender in sausage emulsions. J. Food Sci. 38(2):268-270.

Steffe JF. 1996. Rheological Methods in Food Process Engineering. East Lansing, MI: Freeman Press. P 1-91.

Su YK, Bowers JA, Zayaz JF. 2000. Physical characteristics and microstructure of reduced-fat frankfurters as affected by salt and emulsified fats stabilize with non-meat proteins. J. Food Sci. 65(1):123-128.

Townsend WE, Witnauer LP, Riloff JA, Swift CE. 1968. Comminuted meat emulsions: Differential thermal analysis of fat transitions. Food Technol. 22(3):71-90.

United States Department of Agriculture. 2002. Code of Federal Regulations. Citation 9CFR319.180a (http://www.usda.gov). United States Department of Agriculture. Washington, DC.

Table 3.1. Formulations for pork emulsion from control and experimental samples formulated with a portion of lean replaced by various protein ingredients (Batch size: 1500gm).

	Controls			Treatments	
	Positive for Treatments [a]	Negative for 1% Treatments [b]	Negative for 2% Treatments [c]	1% Treatments [d]	2% Treatments [e]
Ingredient	%	%	%	%	%
Pork Lean [f]	53.50	49.50	45.50	49.50	45.50
Pork Fat [g]	22.00	22.00	22.00	22.00	22.00
Ice	11.50	11.50	11.50	11.50	11.50
Water	11.50	11.50	11.50	11.50	11.50
Salt	1.50	1.50	1.50	1.50	1.50
Treatment	0.00	0.00	0.00	1.00	2.00
Water for Treatment	0.00	4.00	8.00	3.00	6.00
	100.00	100.00	100.00	100.00	100.00

[a] Positive control = No lean meat replacement, same control was used for 1% and 2% treatments.
[b] Negative control for 1% = 4% of the lean meat component in the emulsion formulation was replaced by 4% water.
[c] Negative control for 2% = 8% of the lean meat component in the emulsion formulation was replaced by 8% water.
[d] 1% Treatment = 4% of the lean meat component in the emulsion formulation was replaced by 1% treatment ingredient and 3% water.
[e] 2% Treatment = 8% of the lean meat component in the emulsion formulation was replaced by 2% treatment ingredient and 6% water.
[f] Pork lean = Ham *semimembranosous* (90/10) purchased from Swift and Company (Marshalltown, IA) and trimmed practically free of all visible fat.
[g] Pork fat = Pork backfat purchased from Iowa State University Meat Laboratory (Ames, IA).

Table 3.2. Cooking schedule for frankfurters from control and experimental samples formulated with a portion of lean replaced by various protein ingredients.

Step Type	Step Time	Dry Bulb (°C)	Wet Bulb (°C)	RH [a] (%)	IT [b] (°C)	Main Blower
Cook	00:10:00	43	38	70	-------	4
Cook	00:30:00	63	38	21	-------	10
Cook	00:30:00	63	38	21	-------	2
Cook	00:15:00	68	0	0	-------	7
Steam Cook	00:01:00	82	82	100	71	1
Cold Shower	00:15:00	10	10	0	-------	0

[a] RH = Relative humidity of the smokehouse.
[b] IT = Internal temperature of the product.

Table 3.3. Least squares means for pork emulsion cook yields (%) from control and experimental samples formulated with a portion of lean replaced by various protein ingredients, as measured with a modified Townsend (1968) method.

Treatment	1% Treatment [a]	2% Treatment [b]
Control [c]	79.8 [f]	79.8 [f]
Negative Control [d]	75.4 [h]	71.3 [h]
Gelling Plasma	78.9 [f, i]	80.2 [f, i]
Myogel	80.6 [f, i]	80.1 [f, i]
Myogel Plus	80.0 [f, i]	82.2 [f, i]
Chicken Collagen	79.5 [f, i]	75.1 [g, i]
Turkey Collagen	77.9 [f, h]	76.6 [f, i]
Whey Protein Concentrate	75.8 [g, h]	80.7 [f, i]
Gelling Plasma : Myogel Plus	79.8 [f, i]	78.9 [f, i]
SEM [e]	0.765	

[a] 1% Treatment = 4% of the lean meat component in the emulsion formulation was replaced by 1% treatment ingredient and 3% water.

[b] 2% Treatment = 8% of the lean meat component in the emulsion formulation was replaced by 2% treatment ingredient and 6% water.

[c] Control = No lean meat replacement, same control was used for 1% and 2% treatments.

[d] Negative Control = For the 1% treatments - 4% of the lean meat component in the emulsion formulation was replaced by 4% water.
For the 2% treatments - 8% of the lean meat component in the emulsion formulation was replaced by 8% water.

[e] SEM = Standard error of the means for the yield values of the control and experimental samples.

[fg] Means within the same column with different superscripts are different from the control ($P<0.05$). Significant main effects were separated using the Bonferroni adjusted p-value method for multiple comparisons.

[hi] Means within the same column with different superscripts are different from the negative control ($P<0.05$). Significant main effects were separated using the Bonferroni adjusted p-value method for multiple comparisons.

Table 3.4. Least squares means for water separation (%) and fat separation (%) from control and experimental samples formulated with a portion of lean replaced by various protein ingredients, as measured with a Rongey (1965) method.

	Water Separation		Fat Separation	
Treatment	1% Treatments [a]	2% Treatments [b]	1% Treatments [a]	2% Treatments [b]
Control [c]	20.2 [f]	20.2 [f]	0.8 [f]	0.8 [f]
Negative Control [d]	24.4 [h]	26.0 [h]	1.1 [h]	1.6 [h]
Gelling Plasma	19.4 [f,i]	18.8 [f,i]	0.8 [f,h]	0.7 [f,i]
Myogel	19.2 [f,i]	19.5 [f,i]	0.7 [f,h]	1.1 [f,h]
Myogel Plus	17.5 [f,i]	17.7 [f,i]	0.8 [f,h]	1.0 [f,h]
Chicken Collagen	19.9 [f,i]	21.7 [f,i]	1.1 [f,h]	1.5 [f,h]
Turkey Collagen	19.6 [f,i]	22.1 [f,i]	0.8 [f,h]	1.1 [f,h]
Whey Protein Concentrate	22.4 [f,h]	20.6 [f,i]	1.0 [f,h]	1.4 [f,h]
Gelling Plasma : Myogel Plus	19.2 [f,i]	19.2 [f,i]	0.7 [f,h]	0.8 [f,i]
SEM [e]	0.744		0.141	

[a] 1% Treatment = 4% of the lean meat component in the emulsion formulation was replaced by 1% treatment ingredient and 3% water.
[b] 2% Treatment = 8% of the lean meat component in the emulsion formulation was replaced by 2% treatment ingredient and 6% water.
[c] Control = No lean meat replacement, same control was used for 1% and 2% treatments.
[d] Negative Control = For the 1% treatments - 4% of the lean meat component in the emulsion formulation was replaced by 4% water.
For the 2% treatments - 8% of the lean meat component in the emulsion formulation was replaced by 8% water.
[e] SEM = Standard error of the means for the water and fat separation values of the control and experimental samples.
[fg] Means within the same column with different superscripts are different from the control ($P<0.05$). Significant main effects were separated using the Bonferroni adjusted p-value method for multiple comparisons.
[hi] Means within the same column with different superscripts are different from the negative control ($P<0.05$). Significant main effects were separated using the Bonferroni adjusted p-value method for multiple comparisons.

Table 3.5. Least squares means for raw pH of the emulsion and cooked pH of the finished product from control and experimental samples formulated with a portion of lean replaced by various protein ingredients, as measured with a pH-STAR Pistol (SFK Technology).

	Raw pH		Cooked pH	
Treatment	1% Treatments [a]	2% Treatments [b]	1% Treatments [a]	2% Treatments [b]
Control [c]	5.43 [f]	5.43 [f]	5.84 [f]	5.84 [f]
Negative Control [d]	5.46 [h]	5.46 [h]	5.82 [h]	5.83 [h]
Gelling Plasma	5.50 [f, h]	5.54 [g, h]	5.88 [f, i]	5.88 [f, i]
Myogel	5.51 [f, h]	5.52 [g, h]	5.86 [f, h]	5.88 [f, i]
Myogel Plus	5.51 [f, h]	5.56 [g, i]	5.87 [f, i]	5.89 [g, i]
Chicken Collagen	5.51 [f, h]	5.50 [f, h]	5.87 [f, i]	5.86 [f, h]
Turkey Collagen	5.47 [f, h]	5.52 [g, h]	5.85 [f, h]	5.87 [f, h]
Whey Protein Concentrate	5.56 [g, i]	5.61 [g, i]	5.86 [f, i]	5.93 [g, i]
Gelling Plasma : Myogel Plus	5.51 [f, h]	5.54 [g, h]	5.87 [f, i]	5.88 [f, i]
SEM [e]	0.018		0.010	

[a] 1% Treatment = 4% of the lean meat component in the emulsion formulation was replaced by 1% treatment ingredient and 3% water.
[b] 2% Treatment = 8% of the lean meat component in the emulsion formulation was replaced by 2% treatment ingredient and 6% water.
[c] Control = No lean meat replacement, same control was used for 1% and 2% treatments.
[d] Negative Control = For the 1% treatments - 4% of the lean meat component in the emulsion formulation was replaced by 4% water.
For the 2% treatments - 8% of the lean meat component in the emulsion formulation was replaced by 8% water.
[e] SEM = Standard error of the means for the raw emulsion pH and cooked pH values of the control and experimental samples.
[fg] Means within the same column with different superscripts are different from the control ($P<0.05$). Significant main effects were separated using the Bonferroni adjusted p-value method for multiple comparisons.
[hi] Means within the same column with different superscripts are different from the negative control ($P<0.05$). Significant main effects were separated using the Bonferroni adjusted p-value method for multiple comparisons.

Table 3.6. Least squares means for moisture (%) from control and experimental samples formulated with a portion of lean replaced by various protein ingredients, as measured from cooked emulsion produced by a modified Townsend (1968) method and by an AOAC (1990b) method.

Treatment	1% Treatments [a]	2% Treatments [b]
Control [c]	60.4 [f]	60.4 [f]
Negative Control [d]	59.7 [h]	59.8 [h]
Gelling Plasma	59.5 [f, h]	60.1 [f, h]
Myogel	60.2 [f, h]	61.0 [f, h]
Myogel Plus	58.9 [f, h]	61.0 [f, h]
Chicken Collagen	60.0 [f, h]	60.1 [f, h]
Turkey Collagen	59.7 [f, h]	59.5 [f, h]
Whey Protein Concentrate	59.1 [f, h]	61.2 [f, h]
Gelling Plasma : Myogel Plus	59.5 [f, h]	59.4 [f, h]
SEM [e]	0.355	

[a] 1% Treatment = 4% of the lean meat component in the emulsion formulation was replaced by 1% treatment ingredient and 3% water.

[b] 2% Treatment = 8% of the lean meat component in the emulsion formulation was replaced by 2% treatment ingredient and 6% water.

[c] Control = No lean meat replacement, same control was used for 1% and 2% treatments.

[d] Negative Control = For the 1% treatments - 4% of the lean meat component in the emulsion formulation was replaced by 4% water.
For the 2% treatments - 8% of the lean meat component in the emulsion formulation was replaced by 8% water.

[e] SEM = Standard error of the means for the moisture values of the control and experimental samples.

[fg] Means within the same column with different superscripts are different from the control ($P<0.05$). Significant main effects were separated using the Bonferroni adjusted p-value method for multiple comparisons.

[hi] Means within the same column with different superscripts are different from the negative control ($P<0.05$). Significant main effects were separated using the Bonferroni adjusted p-value method for multiple comparisons.

Table 3.7. Least squares means for fat (%) from control and experimental samples formulated with a portion of lean replaced by various protein ingredients, as measured from cooked emulsion produced by a modified Townsend (1968) method and by an AOAC (1990a) method.

Treatment	1% Treatments [a]	2% Treatments [b]
Control [c]	23.2 [f]	23.2 [f]
Negative Control [d]	24.3 [h]	24.7 [h]
Gelling Plasma	24.2 [f, h]	23.7 [f, h]
Myogel	23.7 [f, h]	23.0 [f, i]
Myogel Plus	23.8 [f, h]	23.2 [f, i]
Chicken Collagen	23.6 [f, h]	23.0 [f, i]
Turkey Collagen	23.8 [f, h]	23.8 [f, h]
Whey Protein Concentrate	23.9 [f, h]	22.7 [f, i]
Gelling Plasma : Myogel Plus	24.1 [f, h]	24.1 [f, h]
SEM [e]	0.289	

[a] 1% Treatment = 4% of the lean meat component in the emulsion formulation was replaced by 1% treatment ingredient and 3% water.

[b] 2% Treatment = 8% of the lean meat component in the emulsion formulation was replaced by 2% treatment ingredient and 6% water.

[c] Control = No lean meat replacement, same control was used for 1% and 2% treatments.

[d] Negative Control = For the 1% treatments - 4% of the lean meat component in the emulsion formulation was replaced by 4% water.
For the 2% treatments - 8% of the lean meat component in the emulsion formulation was replaced by 8% water.

[e] SEM = Standard error of the means for the fat values of the control and experimental samples.

[fg] Means within the same column with different superscripts are different from the control ($P<0.05$). Significant main effects were separated using the Bonferroni adjusted p-value method for multiple comparisons.

[hi] Means within the same column with different superscripts are different from the negative control ($P<0.05$). Significant main effects were separated using the Bonferroni adjusted p-value method for multiple comparisons.

Table 3.8. Least squares means for protein (%) from control and experimental samples formulated with a portion of lean replaced by various protein ingredients, as measured from cooked emulsion produced by a modified Townsend (1968) method and by an AOAC (1993) method.

Treatment	1% Treatments [a]	2% Treatments [b]
Control [c]	14.4 [f]	14.4 [f]
Negative Control [d]	14.2 [h]	13.6 [h]
Gelling Plasma	14.0 [f, h]	13.7 [f, h]
Myogel	14.0 [f, h]	13.9 [f, h]
Myogel Plus	14.1 [f, h]	13.8 [f, h]
Chicken Collagen	14.1 [f, h]	14.8 [f, i]
Turkey Collagen	14.4 [f, h]	14.6 [f, i]
Whey Protein Concentrate	14.6 [f, h]	13.8 [f, h]
Gelling Plasma : Myogel Plus	14.1 [f, h]	14.2 [f, h]
SEM [e]	0.190	

[a] 1% Treatment = 4% of the lean meat component in the emulsion formulation was replaced by 1% treatment ingredient and 3% water.

[b] 2% Treatment = 8% of the lean meat component in the emulsion formulation was replaced by 2% treatment ingredient and 6% water.

[c] Control = No lean meat replacement, same control was used for 1% and 2% treatments.

[d] Negative Control = For the 1% treatments - 4% of the lean meat component in the emulsion formulation was replaced by 4% water.
For the 2% treatments - 8% of the lean meat component in the emulsion formulation was replaced by 8% water.

[e] SEM = Standard error of the means for the protein values of the control and experimental samples.

[fg] Means within the same column with different superscripts are different from the control ($P<0.05$). Significant main effects were separated using the Bonferroni adjusted p-value method for multiple comparisons.

[hi] Means within the same column with different superscripts are different from the negative control ($P<0.05$). Significant main effects were separated using the Bonferroni adjusted p-value method for multiple comparisons.

Table 3.9. Least squares means for ash (%) from control and experimental samples formulated with a portion of lean replaced by various protein ingredients, as measured from cooked emulsion produced by a modified Townsend (1968) method and by the total proximate composition subtracted from 100 percent .

Treatment	1% Treatments [a]	2% Treatments [b]
Control [c]	2.0 [f]	2.0 [f]
Negative Control [d]	1.9 [h]	1.9 [h]
Gelling Plasma	2.3 [f, h]	2.5 [f, i]
Myogel	2.2 [f, h]	2.1 [f, h]
Myogel Plus	2.2 [f, h]	2.1 [f, h]
Chicken Collagen	2.3 [f, h]	2.1 [f, h]
Turkey Collagen	2.1 [f, h]	2.0 [f, h]
Whey Protein Concentrate	2.3 [f, h]	2.3 [f, h]
Gelling Plasma : Myogel Plus	2.4 [f, h]	2.3 [f, h]
SEM [e]	0.125	

[a] 1% Treatment = 4% of the lean meat component in the emulsion formulation was replaced by 1% treatment ingredient and 3% water.

[b] 2% Treatment = 8% of the lean meat component in the emulsion formulation was replaced by 2% treatment ingredient and 6% water.

[c] Control = No lean meat replacement, same control was used for 1% and 2% treatments.

[d] Negative Control = For the 1% treatments - 4% of the lean meat component in the emulsion formulation was replaced by 4% water.
For the 2% treatments - 8% of the lean meat component in the emulsion formulation was replaced by 8% water.

[e] SEM = Standard error of the means for the ash values of the control and experimental samples.

[fg] Means within the same column with different superscripts are different from the control ($P<0.05$). Significant main effects were separated using the Bonferroni adjusted p-value method for multiple comparisons.

[hi] Means within the same column with different superscripts are different from the negative control ($P<0.05$). Significant main effects were separated using the Bonferroni adjusted p-value method for multiple comparisons.

Table 3.10. Least squares means for peak force (gm of force) and internal force (gm of force) from control and experimental tube samples formulated with a portion of lean replaced by various protein ingredients, as measured from cooked emulsion produced by a modified Townsend (1968) method and with a TA.XT2i Texture Analyzer (Texture Technologies Corp.).

	Peak Force		Internal Force	
Treatment	1% Treatments [a]	2% Treatments [b]	1% Treatments [a]	2% Treatments [b]
Control [c]	114 [f]	114 [f]	114 [f]	114 [f]
Negative Control [d]	106 [h]	94 [h]	101 [h]	98 [h]
Gelling Plasma	121 [f,h]	112 [f,h]	125 [f,h]	110 [f,h]
Myogel	100 [f,h]	101 [f,h]	103 [f,h]	101 [f,h]
Myogel Plus	104 [f,h]	94 [f,h]	106 [f,h]	97 [f,h]
Chicken Collagen	102 [f,h]	102 [f,h]	101 [f,h]	107 [f,h]
Turkey Collagen	104 [f,h]	100 [f,h]	107 [f,h]	96 [f,h]
Whey Protein Concentrate	117 [f,h]	99 [f,h]	119 [f,h]	88 [f,h]
Gelling Plasma : Myogel Plus	107 [f,h]	105 [f,h]	105 [f,h]	105 [f,h]
SEM [e]	6.0		7.3	

[a] 1% Treatment = 4% of the lean meat component in the emulsion formulation was replaced by 1% treatment ingredient and 3% water.
[b] 2% Treatment = 8% of the lean meat component in the emulsion formulation was replaced by 2% treatment ingredient and 6% water.
[c] Control = No lean meat replacement, same control was used for 1% and 2% treatments.
[d] Negative Control =For the 1% treatments - 4% of the lean meat component in the emulsion formulation was replaced by 4% water.
For the 2% treatments - 8% of the lean meat component in the emulsion formulation was replaced by 8% water.
[e] SEM = Standard error of the means for the peak force and internal force values of the control and experimental samples.
[fg] Means within the same column with different superscripts are different from the control ($P<0.05$). Significant main effects were separated using the Bonferroni adjusted p-value method for multiple comparisons.
[hi] Means within the same column with different superscripts are different from the negative control ($P<0.05$). Significant main effects were separated using the Bonferroni adjusted p-value method for multiple comparisons.

Table 3.11. Least squares means for peak force (gm of force) and internal force (gm of force) from control and experimental frankfurter-skin off samples formulated with a portion of lean replaced by various protein ingredients, as measured from cooked emulsion produced by a modified Townsend (1968) method and by a TA.XT2i Texture Analyzer (Texture Technologies Corp.).

	Peak Force		Internal Force	
Treatment	1% Treatments [a]	2% Treatments [b]	1% Treatments [a]	2% Treatments [b]
Control [c]	85 [f]	85 [f]	82 [f]	82 [f]
Negative Control [d]	59 [h]	47 [h]	57 [h]	49 [h]
Gelling Plasma	74 [f, h]	67 [g, i]	70 [g, i]	68 [g, i]
Myogel	74 [f, h]	73 [f, i]	72 [f, i]	71 [f, i]
Myogel Plus	80 [f, i]	73 [f, i]	75 [f, i]	68 [g, i]
Chicken Collagen	72 [f, h]	69 [f, i]	70 [g, i]	70 [g, i]
Turkey Collagen	75 [f, h]	64 [g, h]	74 [f, i]	63 [g, i]
Whey Protein Concentrate	74 [f, h]	93 [f, i]	78 [f, i]	79 [f, i]
Gelling Plasma : Myogel Plus	80 [f, i]	83 [f, i]	75 [f, i]	73 [f, i]
SEM [e]	4.0		2.6	

[a] 1% Treatment = 4% of the lean meat component in the emulsion formulation was replaced by 1% treatment ingredient and 3% water.
[b] 2% Treatment = 8% of the lean meat component in the emulsion formulation was replaced by 2% treatment ingredient and 6% water.
[c] Control = No lean meat replacement, same control was used for 1% and 2% treatments.
[d] Negative Control = For the 1% treatments - 4% of the lean meat component in the emulsion formulation was replaced by 4% water.
For the 2% treatments - 8% of the lean meat component in the emulsion formulation was replaced by 8% water.
[e] SEM = Standard error of the means for the peak force and internal force values of the control and experimental samples.
[fg] Means within the same column with different superscripts are different from the control ($P<0.05$). Significant main effects were separated using the Bonferroni adjusted p-value method for multiple comparisons.
[hi] Means within the same column with different superscripts are different from the negative control ($P<0.05$). Significant main effects were separated using the Bonferroni adjusted p-value method for multiple comparisons.

Table 3.12. Least squares means for peak force (gm of force) and internal force (gm of force) from control and experimental frankfurter-skin on samples formulated with a portion of lean replaced by various protein ingredients, as measured from cooked emulsion produced by a modified Townsend (1968) method and by a TA.XT2i Texture Analyzer (Texture Technologies Corp.).

	Peak Force		Internal Force	
Treatment	1% Treatments [a]	2% Treatments [b]	1% Treatments [a]	2% Treatments [b]
Control [c]	181 [f]	181 [f]	81 [f]	81 [f]
Negative Control [d]	158 [h]	148 [h]	61 [h]	56 [h]
Gelling Plasma	178 [f,h]	180 [f,h]	79 [f,h]	75 [f,i]
Myogel	177 [f,h]	172 [f,h]	82 [f,i]	84 [f,i]
Myogel Plus	177 [f,h]	169 [f,h]	80 [f,i]	83 [f,i]
Chicken Collagen	163 [f,h]	165 [f,h]	77 [f,h]	83 [f,i]
Turkey Collagen	172 [f,h]	153 [f,h]	79 [f,h]	69 [f,h]
Whey Protein Concentrate	184 [f,h]	209 [f,i]	95 [f,i]	85 [f,i]
Gelling Plasma : Myogel Plus	197 [f,h]	176 [f,h]	85 [f,i]	78 [f,i]
SEM [e]	9.7		4.2	

[a] 1% Treatment = 4% of the lean meat component in the emulsion formulation was replaced by 1% treatment ingredient and 3% water.
[b] 2% Treatment = 8% of the lean meat component in the emulsion formulation was replaced by 2% treatment ingredient and 6% water.
[c] Control = No lean meat replacement, same control was used for 1% and 2% treatments.
[d] Negative Control = For the 1% treatments - 4% of the lean meat component in the emulsion formulation was replaced by 4% water.
For the 2% treatments - 8% of the lean meat component in the emulsion formulation was replaced by 8% water.
[e] SEM = Standard error of the means for the peak force and internal force values of the control and experimental samples.
[fg] Means within the same column with different superscripts are different from the control ($P<0.05$). Significant main effects were separated using the Bonferroni adjusted p-value method for multiple comparisons.
[hi] Means within the same column with different superscripts are different from the negative control ($P<0.05$). Significant main effects were separated using the Bonferroni adjusted p-value method for multiple comparisons.

Table 3.13. Least squares means for cohesiveness and chewiness (gm of force) from control and experimental tube samples formulated with a portion of lean replaced by various protein ingredients, as measured from cooked emulsion produced by a modified Townsend (1968) method and by a TA.XT2i Texture Analyzer (Texture Technologies Corp.).

	Cohesiveness		Chewiness	
Treatment	1% Treatments [a]	2% Treatments [b]	1% Treatments [a]	2% Treatments [b]
Control [c]	0.32 [f]	0.32 [f]	5270 [f]	5270 [f]
Negative Control [d]	0.26 [h]	0.26 [h]	3360 [h]	1920 [h]
Gelling Plasma	0.30 [f, h]	0.28 [f, h]	6630 [f, h]	5490 [f, h]
Myogel	0.28 [f, h]	0.27 [f, h]	4540 [f, h]	4570 [f, h]
Myogel Plus	0.37 [f, i]	0.33 [f, i]	7140 [f, h]	7110 [f, h]
Chicken Collagen	0.29 [f, h]	0.26 [f, h]	4620 [f, h]	2930 [f, h]
Turkey Collagen	0.26 [f, h]	0.25 [f, h]	3340 [f, h]	2950 [f, h]
Whey Protein Concentrate	0.31 [f, h]	0.28 [f, h]	5295 [f, h]	4570 [f, h]
Gelling Plasma : Myogel Plus	0.30 [f, h]	0.32 [f, i]	5050 [f, h]	8950 [f, i]
SEM [e]	0.015		1210	

[a] 1% Treatment = 4% of the lean meat component in the emulsion formulation was replaced by 1% treatment ingredient and 3% water.
[b] 2% Treatment = 8% of the lean meat component in the emulsion formulation was replaced by 2% treatment ingredient and 6% water.
[c] Control = No lean meat replacement, same control was used for 1% and 2% treatments.
[d] Negative Control = For the 1% treatments - 4% of the lean meat component in the emulsion formulation was replaced by 4% water.
For the 2% treatments - 8% of the lean meat component in the emulsion formulation was replaced by 8% water.
[e] SEM = Standard error of the means for the cohesiveness and chewiness values of the control and experimental samples.
[fg] Means within the same column with different superscripts are different from the control ($P<0.05$). Significant main effects were separated using the Bonferroni adjusted p-value method for multiple comparisons.
[hi] Means within the same column with different superscripts are different from the negative control ($P<0.05$). Significant main effects were separated using the Bonferroni adjusted p-value method for multiple comparisons.

Table 3.14. Least squares means for springiness (mm of distance) and hardness (gm of force) from control and experimental tube samples formulated with a portion of lean replaced by various protein ingredients, as measured from cooked emulsion produced by a modified Townsend (1968) method and by a TA.XT2i Texture Analyzer (Texture Technologies Corp.).

	Springiness		Hardness	
Treatment	1% Treatments [a]	2% Treatments [b]	1% Treatments [a]	2% Treatments [b]
Control [c]	8.25 [f]	8.25 [f]	3580 [f]	3580 [f]
Negative Control [d]	7.73 [h]	6.75 [h]	2630 [h]	1900 [h]
Gelling Plasma	9.51 [f, h]	10.08 [f, i]	3600 [f, h]	2980 [f, h]
Myogel	7.84 [f, h]	8.02 [f, h]	3090 [f, h]	2610 [f, h]
Myogel Plus	8.91 [f, h]	8.92 [f, h]	3140 [f, h]	2940 [f, h]
Chicken Collagen	8.61 [f, h]	7.21 [f, h]	2790 [f, h]	1600 [g, h]
Turkey Collagen	7.50 [f, h]	7.35 [f, h]	2420 [f, h]	2450 [f, h]
Whey Protein Concentrate	7.91 [f, h]	8.73 [f, h]	2820 [f, h]	2300 [g, h]
Gelling Plasma : Myogel Plus	8.65 [f, h]	9.23 [f, i]	2650 [f, h]	3020 [f, h]
SEM [e]	0.497		265	

[a] 1% Treatment = 4% of the lean meat component in the emulsion formulation was replaced by 1% treatment ingredient and 3% water.
[b] 2% Treatment = 8% of the lean meat component in the emulsion formulation was replaced by 2% treatment ingredient and 6% water.
[c] Control = No lean meat replacement, same control was used for 1% and 2% treatments.
[d] Negative Control = For the 1% treatments - 4% of the lean meat component in the emulsion formulation was replaced by 4% water.
For the 2% treatments - 8% of the lean meat component in the emulsion formulation was replaced by 8% water.
[e] SEM = Standard error of the means for the springiness and hardness values of the control and experimental samples.
[fg] Means within the same column with different superscripts are different from the control ($P<0.05$). Significant main effects were separated using the Bonferroni adjusted p-value method for multiple comparisons.
[hi] Means within the same column with different superscripts are different from the negative control ($P<0.05$). Significant main effects were separated using the Bonferroni adjusted p-value method for multiple comparisons.

Table 3.15. Least squares means for cohesiveness and chewiness (gm of force) from control and experimental tube core samples formulated with a portion of lean replaced by various protein ingredients, as measured from cooked emulsion produced by a modified Townsend (1968) method and by a TA.XT2i Texture Analyzer (Texture Technologies Corp.).

	Cohesiveness		Chewiness	
Treatment	1% Treatments [a]	2% Treatments [b]	1% Treatments [a]	2% Treatments [b]
Control [c]	0.29 [f]	0.29 [f]	1680 [f]	1680 [f]
Negative Control [d]	0.26 [h]	0.22 [h]	1320 [h]	620 [h]
Gelling Plasma	0.27 [f, h]	0.26 [f, h]	2070 [f, h]	2030 [f, i]
Myogel	0.26 [f, h]	0.25 [f, h]	1620 [f, h]	1430 [f, h]
Myogel Plus	0.26 [f, h]	0.28 [f, i]	1660 [f, h]	1970 [f, i]
Chicken Collagen	0.26 [f, h]	0.25 [f, h]	1310 [f, h]	1100 [f, h]
Turkey Collagen	0.29 [f, h]	0.25 [f, h]	1450 [f, h]	1090 [f, h]
Whey Protein Concentrate	0.28 [f, h]	0.25 [f, h]	1920 [f, h]	1670 [f, h]
Gelling Plasma : Myogel Plus	0.28 [f, h]	0.27 [f, h]	2120 [f, h]	2760 [f, i]
SEM [e]	0.011		250	

[a] 1% Treatment = 4% of the lean meat component in the emulsion formulation was replaced by 1% treatment ingredient and 3% water.
[b] 2% Treatment = 8% of the lean meat component in the emulsion formulation was replaced by 2% treatment ingredient and 6% water.
[c] Control = No lean meat replacement, same control was used for 1% and 2% treatments.
[d] Negative Control = For the 1% treatments - 4% of the lean meat component in the emulsion formulation was replaced by 4% water.
For the 2% treatments - 8% of the lean meat component in the emulsion formulation was replaced by 8% water.
[e] SEM = Standard error of the means for the cohesiveness and chewiness values of the control and experimental samples.
[fg] Means within the same column with different superscripts are different from the control ($P<0.05$). Significant main effects were separated using the Bonferroni adjusted p-value method for multiple comparisons.
[hi] Means within the same column with different superscripts are different from the negative control ($P<0.05$). Significant main effects were separated using the Bonferroni adjusted p-value method for multiple comparisons.

Table 3.16. Least squares means for springiness (mm of distance) and hardness (gm of force) from control and experimental tube core samples formulated with a portion of lean replaced by various protein ingredients, as measured from cooked emulsion produced by a modified Townsend (1968) method and by a TA.XT2i Texture Analyzer (Texture Technologies Corp.).

	Springiness		Hardness	
Treatment	1% Treatments [a]	2% Treatments [b]	1% Treatments [a]	2% Treatments [b]
Control [c]	6.27 [f]	6.27 [f]	2130 [f]	2130 [f]
Negative Control [d]	5.34 [h]	4.72 [h]	1700 [h]	1270 [h]
Gelling Plasma	7.20 [f, h]	6.16 [f, h]	2240 [f, h]	1760 [f, h]
Myogel	5.75 [f, h]	6.07 [f, h]	1760 [f, h]	1730 [f, h]
Myogel Plus	6.31 [f, h]	7.08 [f, i]	2110 [f, h]	1960 [f, i]
Chicken Collagen	5.54 [f, h]	5.85 [f, h]	1770 [f, h]	1640 [f, h]
Turkey Collagen	6.04 [f, h]	5.62 [f, h]	1800 [f, h]	1530 [g, h]
Whey Protein Concentrate	6.40 [f, h]	7.14 [f, i]	2070 [f, h]	1550 [g, h]
Gelling Plasma : Myogel Plus	7.14 [f, h]	6.95 [f, i]	1640 [f, h]	1780 [f, h]
SEM [e]	0.47		129	

[a] 1% Treatment = 4% of the lean meat component in the emulsion formulation was replaced by 1% treatment ingredient and 3% water.
[b] 2% Treatment = 8% of the lean meat component in the emulsion formulation was replaced by 2% treatment ingredient and 6% water.
[c] Control = No lean meat replacement, same control was used for 1% and 2% treatments.
[d] Negative Control = For the 1% treatments - 4% of the lean meat component in the emulsion formulation was replaced by 4% water.
For the 2% treatments - 8% of the lean meat component in the emulsion formulation was replaced by 8% water.
[e] SEM = Standard error of the means for the springiness and hardness values of the control and experimental samples.
[fg] Means within the same column with different superscripts are different from the control ($P<0.05$). Significant main effects were separated using the Bonferroni adjusted p-value method for multiple comparisons.
[hi] Means within the same column with different superscripts are different from the negative control ($P<0.05$). Significant main effects were separated using the Bonferroni adjusted p-value method for multiple comparisons.

Table 3.17. Least squares means for cohesiveness and chewiness (gm of force) from control and experimental frankfurter-skin off samples formulated with a portion of lean replaced by various protein ingredients, as measured from cooked emulsion produced by a modified Townsend (1968) method and by a TA.XT2i Texture Analyzer (Texture Technologies Corp.).

	Cohesiveness		Chewiness	
Treatment	1% Treatments [a]	2% Treatments [b]	1% Treatments [a]	2% Treatments [b]
Control [c]	0.29	0.29	2070 [f]	2070 [f]
Negative Control [d]	0.30	0.26	1300 [h]	490 [h]
Gelling Plasma	0.30	0.28	2070 [f, h]	1850 [f, h]
Myogel	0.31	0.31	2530 [f, h]	2230 [f, h]
Myogel Plus	0.29	0.30	2060 [f, h]	2280 [f, h]
Chicken Collagen	0.31	0.27	1850 [f, h]	1280 [f, h]
Turkey Collagen	0.29	0.28	1640 [f, h]	1220 [f, h]
Whey Protein Concentrate	0.29	0.31	1710 [f, h]	2440 [f, i]
Gelling Plasma : Myogel Plus	0.30	0.31	2360 [f, h]	3190 [f, i]
SEM [e]	0.013		394	

[a] 1% Treatment = 4% of the lean meat component in the emulsion formulation was replaced by 1% treatment ingredient and 3% water.
[b] 2% Treatment = 8% of the lean meat component in the emulsion formulation was replaced by 2% treatment ingredient and 6% water.
[c] Control = No lean meat replacement, same control was used for 1% and 2% treatments.
[d] Negative Control = For the 1% treatments - 4% of the lean meat component in the emulsion formulation was replaced by 4% water.
For the 2% treatments - 8% of the lean meat component in the emulsion formulation was replaced by 8% water.
[e] SEM = Standard error of the means for the cohesiveness and chewiness values of the control and experimental samples.
[fg] Means within the same column with different superscripts are different from the control ($P<0.05$). Significant main effects were separated using the Bonferroni adjusted p-value method for multiple comparisons.
[hi] Means within the same column with different superscripts are different from the negative control ($P<0.05$). Significant main effects were separated using the Bonferroni adjusted p-value method for multiple comparisons.

Table 3.18. Least squares means for springiness (mm of distance) and hardness (gm of force) from control and experimental frankfurter-skin off samples formulated with a portion of lean replaced by various protein ingredients, as measured from cooked emulsion produced by a modified Townsend (1968) method and by a TA.XT2i Texture Analyzer (Texture Technologies Corp.).

	Springiness		Hardness	
Treatment	1% Treatments [a]	2% Treatments [b]	1% Treatments [a]	2% Treatments [b]
Control [c]	7.17 [f]	7.17 [f]	1530 [f]	1530 [f]
Negative Control [d]	5.99 [h]	4.81 [h]	1010 [h]	810 [h]
Gelling Plasma	6.79 [f, h]	6.95 [f, h]	1250 [f, h]	1370 [f, i]
Myogel	6.97 [f, h]	6.82 [f, h]	1560 [f, i]	1490 [f, i]
Myogel Plus	6.28 [f, h]	6.40 [f, h]	1470 [f, i]	1550 [f, i]
Chicken Collagen	7.54 [f, h]	5.33 [f, h]	1280 [f, h]	1260 [f, i]
Turkey Collagen	7.03 [f, h]	5.44 [f, h]	1270 [f, h]	1150 [f, h]
Whey Protein Concentrate	8.03 [f, h]	9.97 [f, i]	1500 [f, i]	1430 [f, i]
Gelling Plasma : Myogel Plus	7.42 [f, h]	8.09 [f, i]	1490 [f, i]	1450 [f, i]
SEM [e]	0.667		88	

[a] 1% Treatment = 4% of the lean meat component in the emulsion formulation was replaced by 1% treatment ingredient and 3% water.
[b] 2% Treatment = 8% of the lean meat component in the emulsion formulation was replaced by 2% treatment ingredient and 6% water.
[c] Control = No lean meat replacement, same control was used for 1% and 2% treatments.
[d] Negative Control = For the 1% treatments - 4% of the lean meat component in the emulsion formulation was replaced by 4% water.
For the 2% treatments - 8% of the lean meat component in the emulsion formulation was replaced by 8% water.
[e] SEM = Standard error of the means for the springiness and hardness values of the control and experimental samples.
[fg] Means within the same column with different superscripts are different from the control ($P<0.05$). Significant main effects were separated using the Bonferroni adjusted p-value method for multiple comparisons.
[hi] Means within the same column with different superscripts are different from the negative control ($P<0.05$). Significant main effects were separated using the Bonferroni adjusted p-value method for multiple comparisons.

Table 3.19. Least squares means for cohesiveness and chewiness (gm of force) from control and experimental frankfurter-skin on samples formulated with a portion of lean replaced by various protein ingredients, as measured from cooked emulsion produced by a modified Townsend (1968) method and by a TA.XT2i Texture Analyzer (Texture Technologies Corp.).

	Cohesiveness		Chewiness	
Treatment	1% Treatments [a]	2% Treatments [b]	1% Treatments [a]	2% Treatments [b]
Control [c]	0.29 [f]	0.29 [f]	3390 [f]	3390 [f]
Negative Control [d]	0.29 [h]	0.30 [h]	2350 [h]	1700 [h]
Gelling Plasma	0.28 [f, h]	0.31 [f, h]	2960 [f, h]	3870 [f, h]
Myogel	0.33 [f, h]	0.36 [g, h]	4350 [f, h]	4420 [f, i]
Myogel Plus	0.32 [f, h]	0.33 [f, h]	3710 [f, h]	4170 [f, i]
Chicken Collagen	0.35 [f, h]	0.33 [f, h]	3910 [f, h]	2300 [f, h]
Turkey Collagen	0.36 [g, i]	0.30 [f, h]	3250 [f, h]	1650 [f, h]
Whey Protein Concentrate	0.33 [f, h]	0.32 [f, h]	3390 [f, h]	3030 [f, h]
Gelling Plasma : Myogel Plus	0.34 [f, h]	0.36 [g, h]	3570 [f, h]	4330 [f, i]
SEM [e]	0.013		457	

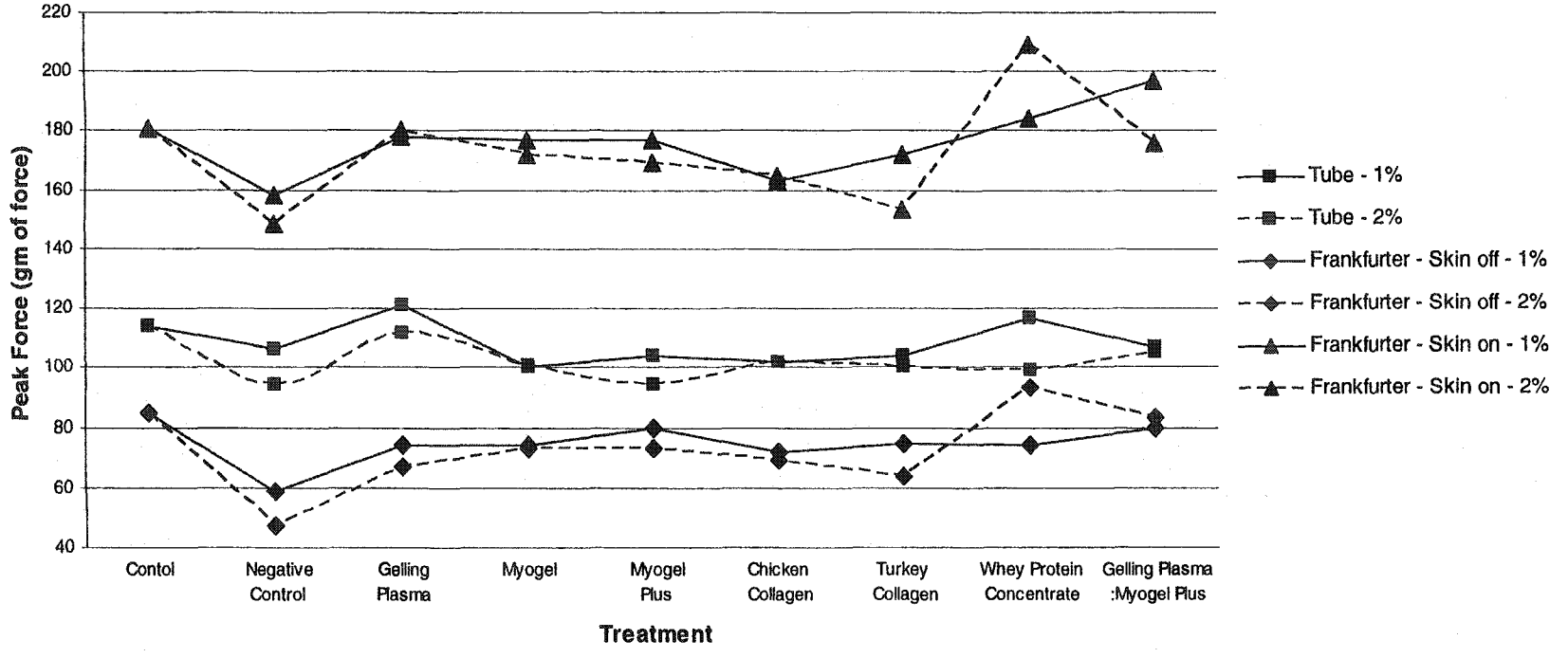
[a] 1% Treatment = 4% of the lean meat component in the emulsion formulation was replaced by 1% treatment ingredient and 3% water.
[b] 2% Treatment = 8% of the lean meat component in the emulsion formulation was replaced by 2% treatment ingredient and 6% water.
[c] Control = No lean meat replacement, same control was used for 1% and 2% treatments.
[d] Negative Control = For the 1% treatments - 4% of the lean meat component in the emulsion formulation was replaced by 4% water.
For the 2% treatments - 8% of the lean meat component in the emulsion formulation was replaced by 8% water.
[e] SEM = Standard error of the means for the cohesiveness and chewiness values of the control and experimental samples.
[fg] Means within the same column with different superscripts are different from the control ($P<0.05$). Significant main effects were separated using the Bonferroni adjusted p-value method for multiple comparisons.
[hi] Means within the same column with different superscripts are different from the negative control ($P<0.05$). Significant main effects were separated using the Bonferroni adjusted p-value method for multiple comparisons.

Table 3.20. Least squares means for springiness (mm of distance) and hardness (gm of force) from control and experimental frankfurter-skin on samples formulated with a portion of lean replaced by various protein ingredients, as measured from cooked emulsion produced by a modified Townsend (1968) method and by a TA.XT2i Texture Analyzer (Texture Technologies Corp.).

	Springiness		Hardness	
Treatment	1% Treatments [a]	2% Treatments [b]	1% Treatments [a]	2% Treatments [b]
Control [c]	7.37 [f]	7.37 [f]	1760 [f]	1760 [f]
Negative Control [d]	5.68 [h]	4.99 [h]	1400 [h]	1160 [h]
Gelling Plasma	7.70 [f, h]	7.49 [f, h]	1710 [f, h]	1690 [f, i]
Myogel	6.67 [f, h]	6.44 [f, h]	2060 [f, i]	1940 [f, i]
Myogel Plus	7.76 [f, h]	7.24 [f, h]	1840 [f, h]	2060 [f, i]
Chicken Collagen	7.30 [f, h]	5.87 [f, h]	1440 [f, h]	1620 [f, h]
Turkey Collagen	6.79 [f, h]	5.89 [f, h]	1780 [f, h]	1630 [f, h]
Whey Protein Concentrate	8.11 [f, h]	10.46 [g, i]	1720 [f, h]	1620 [f, h]
Gelling Plasma : Myogel Plus	8.17 [f, h]	8.28 [f, i]	1800 [f, h]	1850 [f, i]
SEM [e]	0.582		104	

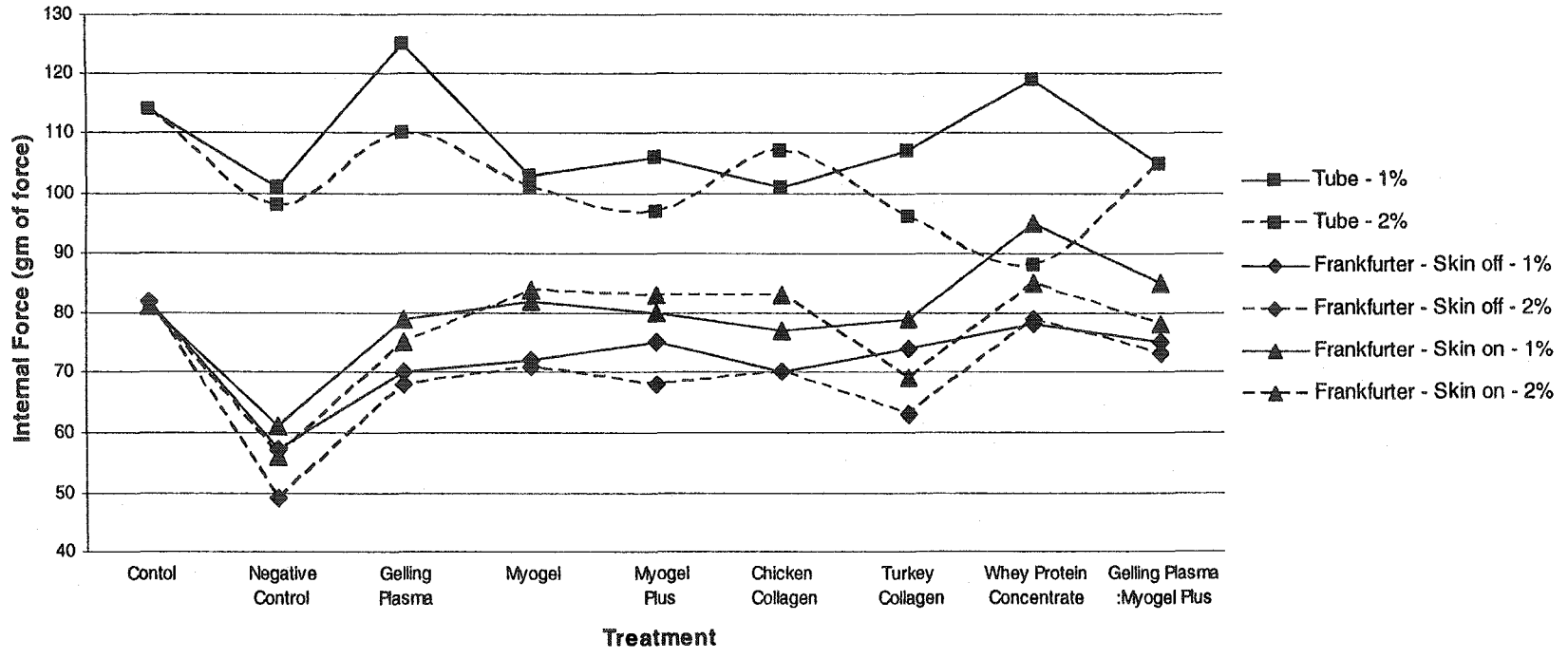
[a] 1% Treatment = 4% of the lean meat component in the emulsion formulation was replaced by 1% treatment ingredient and 3% water.
[b] 2% Treatment = 8% of the lean meat component in the emulsion formulation was replaced by 2% treatment ingredient and 6% water.
[c] Control = No lean meat replacement, same control was used for 1% and 2% treatments.
[d] Negative Control = For the 1% treatments - 4% of the lean meat component in the emulsion formulation was replaced by 4% water.
For the 2% treatments - 8% of the lean meat component in the emulsion formulation was replaced by 8% water.
[e] SEM = Standard error of the means for the springiness and hardness values of the control and experimental samples.
[fg] Means within the same column with different superscripts are different from the control ($P<0.05$). Significant main effects were separated using the Bonferroni adjusted p-value method for multiple comparisons.
[hi] Means within the same column with different superscripts are different from the negative control ($P<0.05$). Significant main effects were separated using the Bonferroni adjusted p-value method for multiple comparisons.

Figure 3.1. Least squares means for peak force (gm of force) from control[ab] samples and experimental samples formulated with a portion of lean replaced[cd] by various protein ingredients, as measured from cooked emulsion produced by a modified Townsend (1968) method and with a TA.XT2i Texture Analyzer (Texture Technologies Corp.).



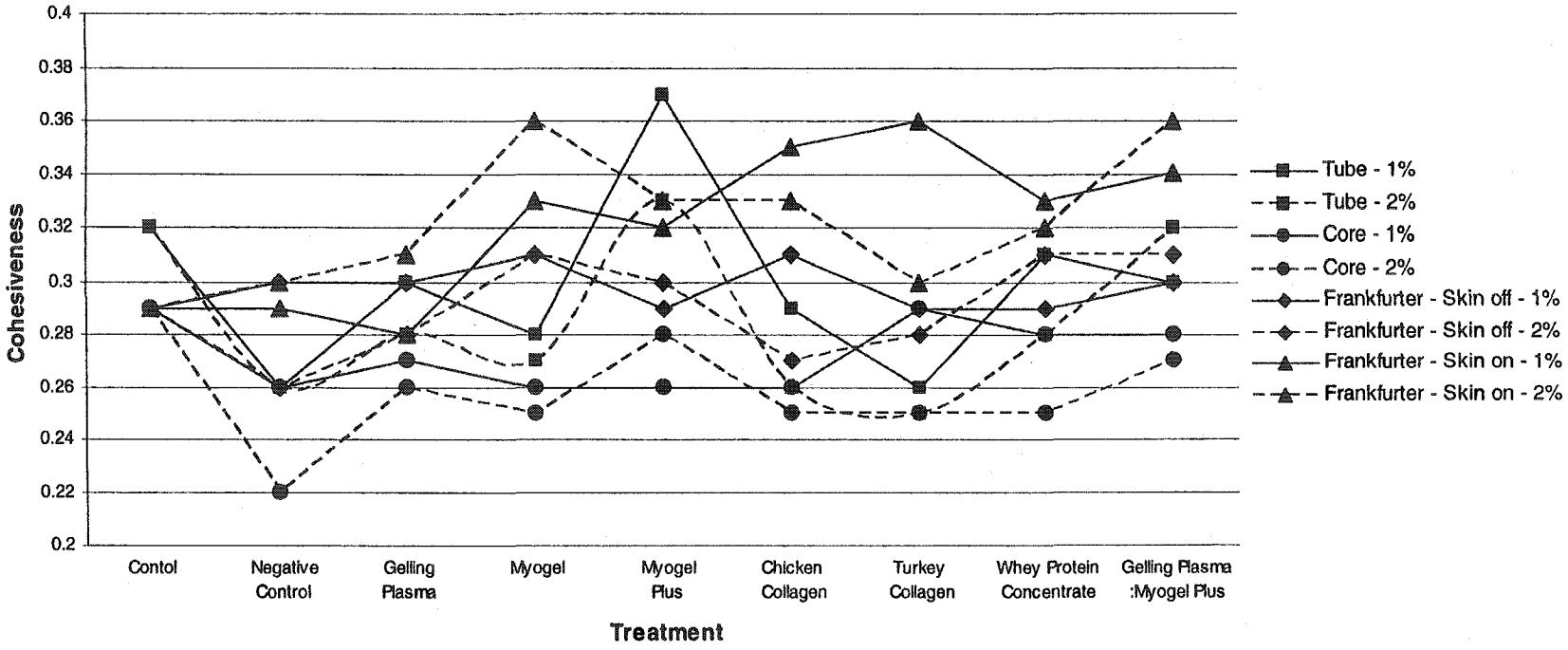
[a] Control = No lean meat replacement, same control was used for 1% and 2% treatments.
[b] Negative Control = For the 1% treatments - 4% of the lean meat component in the emulsion formulation was replaced by 4% water.
For the 2% treatments - 8% of the lean meat component in the emulsion formulation was replaced by 8% water.
[c] 1% Treatment = 4% of the lean meat component in the emulsion formulation was replaced by 1% treatment ingredient and 3% water.
[d] 2% Treatment = 8% of the lean meat component in the emulsion formulation was replaced by 2% treatment ingredient and 6% water.

Figure 3.2. Least squares means for internal force (gm of force) from control[ab] samples and experimental samples formulated with a portion of lean replaced[cd] by various protein ingredients, as measured from cooked emulsion produced by a modified Townsend (1968) method and with a TA.XT2i Texture Analyzer (Texture Technologies Corp.).



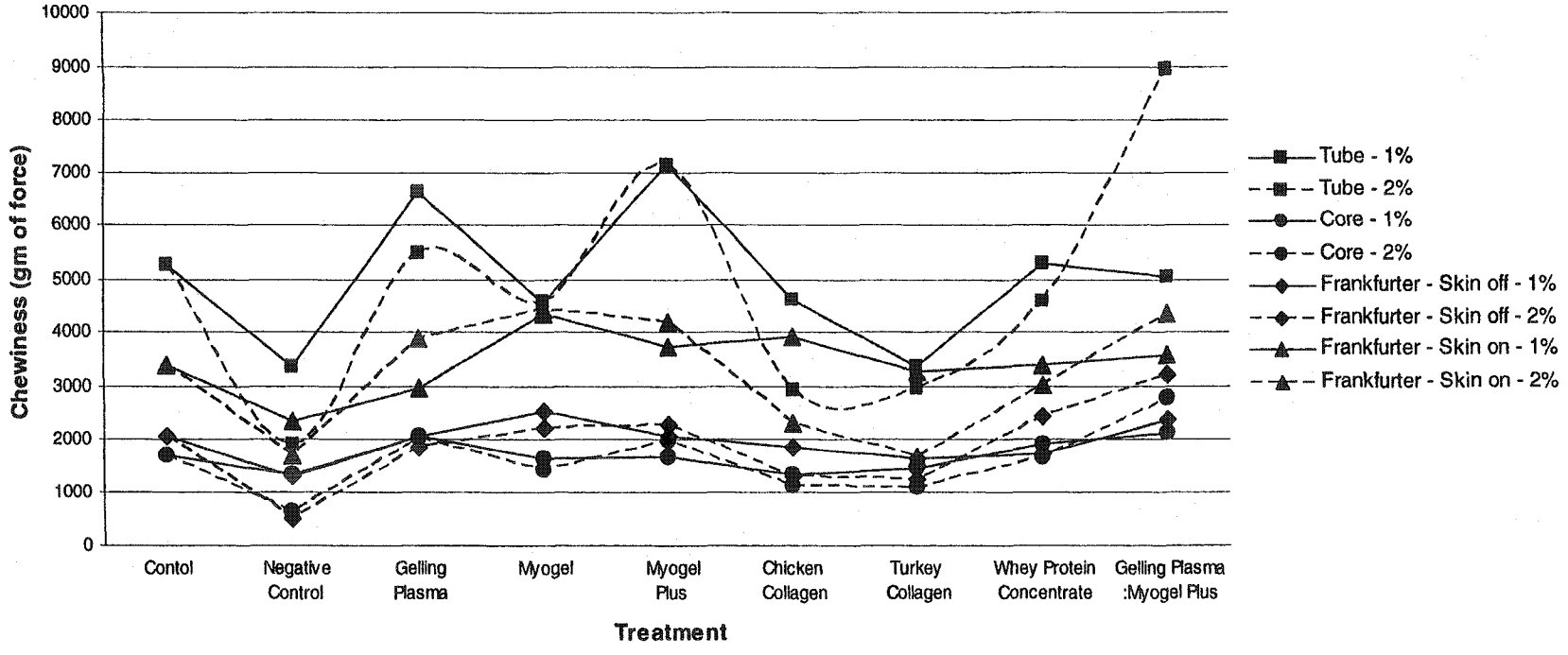
[a] Control = No lean meat replacement, same control was used for 1% and 2% treatments.
[b] Negative Control = For the 1% treatments - 4% of the lean meat component in the emulsion formulation was replaced by 4% water.
For the 2% treatments - 8% of the lean meat component in the emulsion formulation was replaced by 8% water.
[c] 1% Treatment = 4% of the lean meat component in the emulsion formulation was replaced by 1% treatment ingredient and 3% water.
[d] 2% Treatment = 8% of the lean meat component in the emulsion formulation was replaced by 2% treatment ingredient and 6% water.

Figure 3.3. Least squares means for cohesiveness from control[ab] samples and experimental tube samples formulated with a portion of lean replaced[cd] by various protein ingredients, as measured from cooked emulsion produced by a modified Townsend (1968) method and by a TA.XT2i Texture Analyzer (Texture Technologies Corp.).



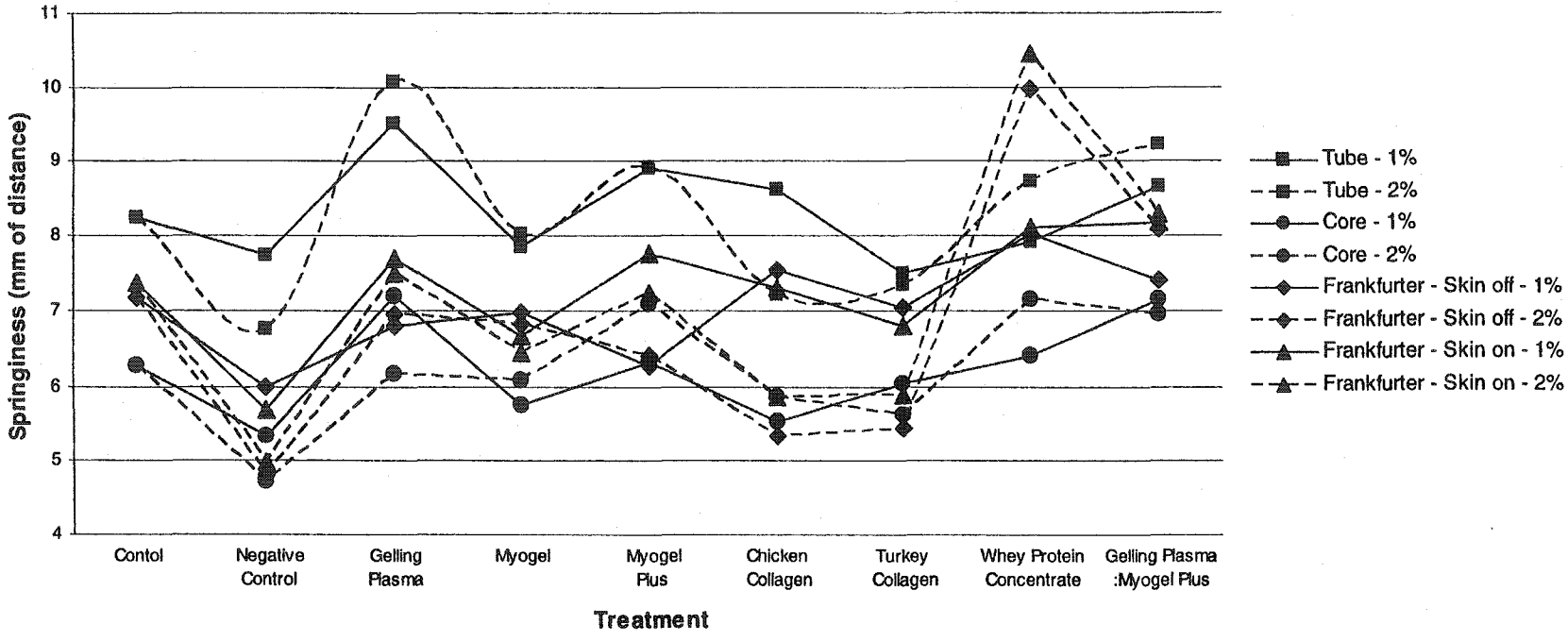
[a] Control = No lean meat replacement, same control was used for 1% and 2% treatments.
[b] Negative Control = For the 1% treatments - 4% of the lean meat component in the emulsion formulation was replaced by 4% water.
For the 2% treatments - 8% of the lean meat component in the emulsion formulation was replaced by 8% water.
[c] 1% Treatment = 4% of the lean meat component in the emulsion formulation was replaced by 1% treatment ingredient and 3% water.
[d] 2% Treatment = 8% of the lean meat component in the emulsion formulation was replaced by 2% treatment ingredient and 6% water.

Table 3.4. Least squares means for chewiness (gm of force) from control[ab] samples and experimental tube samples formulated with a portion of lean replaced[cd] by various protein ingredients, as measured from cooked emulsion produced by a modified Townsend (1968) method and by a TA.XT2i Texture Analyzer (Texture Technologies Corp.).



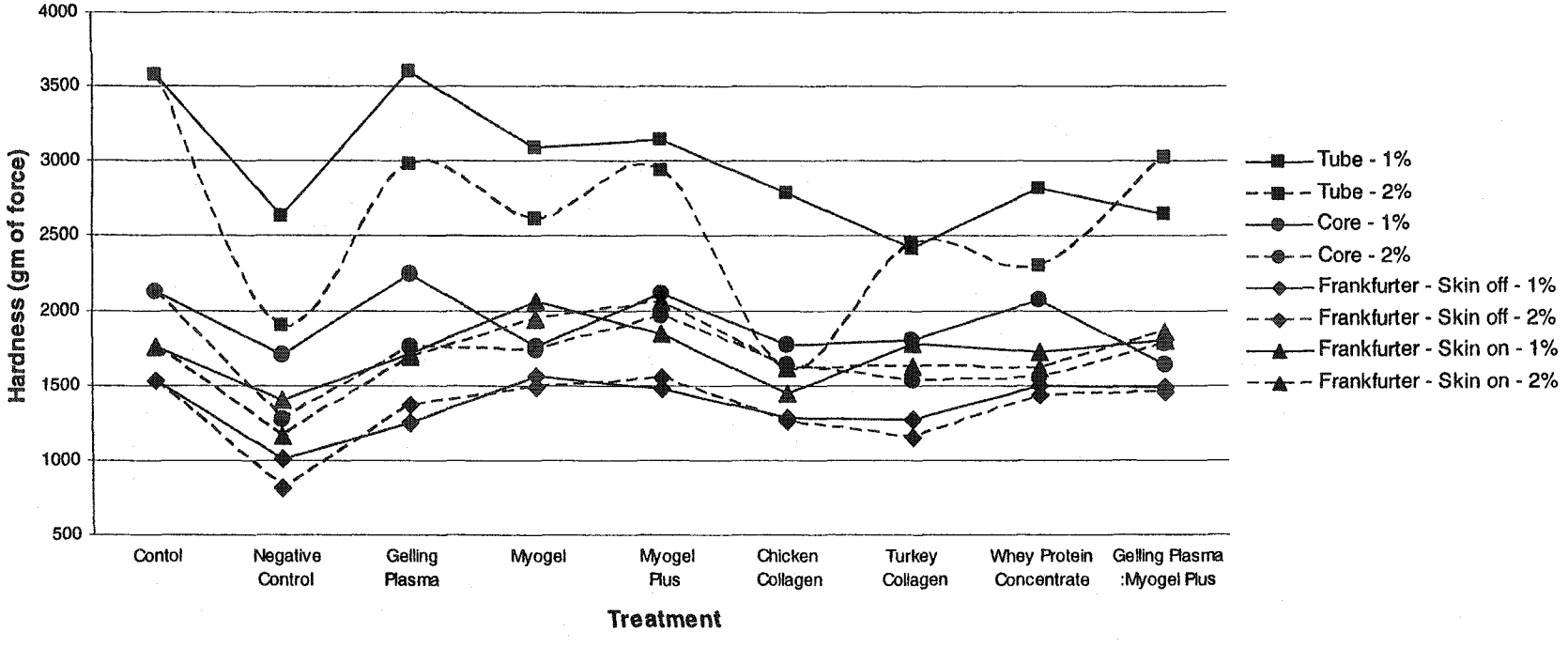
[a] Control = No lean meat replacement, same control was used for 1% and 2% treatments.
[b] Negative Control = For the 1% treatments - 4% of the lean meat component in the emulsion formulation was replaced by 4% water.
For the 2% treatments - 8% of the lean meat component in the emulsion formulation was replaced by 8% water.
[c] 1% Treatment = 4% of the lean meat component in the emulsion formulation was replaced by 1% treatment ingredient and 3% water.
[d] 2% Treatment = 8% of the lean meat component in the emulsion formulation was replaced by 2% treatment ingredient and 6% water.

Figure 3.5. Least squares means for springiness (mm of distance) from control[ab] samples and experimental tube samples formulated with a portion of lean replaced[cd] by various protein ingredients, as measured from cooked emulsion produced by a modified Townsend (1968) method and by a TA.XT2i Texture Analyzer (Texture Technologies Corp.).



[a] Control = No lean meat replacement, same control was used for 1% and 2% treatments.
[b] Negative Control = For the 1% treatments - 4% of the lean meat component in the emulsion formulation was replaced by 4% water.
For the 2% treatments - 8% of the lean meat component in the emulsion formulation was replaced by 8% water.
[c] 1% Treatment = 4% of the lean meat component in the emulsion formulation was replaced by 1% treatment ingredient and 3% water.
[d] 2% Treatment = 8% of the lean meat component in the emulsion formulation was replaced by 2% treatment ingredient and 6% water.

Figure 3.6. Least squares means for hardness (gm of force) from control[ab] samples and experimental tube samples formulated with a portion of lean replaced[cd] by various protein ingredients, as measured from cooked emulsion produced by a modified Townsend (1968) method and by a TA.XT2i Texture Analyzer (Texture Technologies Corp.).



[a] Control = No lean meat replacement, same control was used for 1% and 2% treatments.
[b] Negative Control = For the 1% treatments - 4% of the lean meat component in the emulsion formulation was replaced by 4% water.
For the 2% treatments - 8% of the lean meat component in the emulsion formulation was replaced by 8% water.
[c] 1% Treatment = 4% of the lean meat component in the emulsion formulation was replaced by 1% treatment ingredient and 3% water.
[d] 2% Treatment = 8% of the lean meat component in the emulsion formulation was replaced by 2% treatment ingredient and 6% water.

CHAPTER 4. THE EFFECT OF LEAN MEAT REPLACEMENT BY VARIOUS PROTEIN INGREDIENTS ON THE PROPERTIES OF FRANKFURTERS AND MODEL EMULSION SYSTEM

A paper to be submitted to The *Journal of Food Science*

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Abstract

The effects of replacing a portion of the lean meat block with various protein ingredients in frankfurter formulations were measured. The characteristics measured included smokehouse yield, proximate composition (moisture, fat, protein, ash), color (CIE L*, a*, b*), purge, texture, and sensory attributes. A majority of the treatments displayed equivalent or improved attributes when compared to the control. A majority of the puncture and texture attributes of treated samples were similar to the control, while sensory attributes were altered. Most attributes measured in the model emulsions system did not significantly correlate to the same attributes measured in the frankfurter system. The results indicated that the utilization of this lean meat replacement processing technology will yield frankfurters with many attributes equivalent to frankfurters with no lean replacement.

Keywords: Meat Replacement, Protein Ingredients

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Introduction

It is well documented that the world population is growing, but the resources to sustain such populations are maintained at the same rate. Meat and meat products provide proteins which are important because they are the only dietary sources of amino acids. Advances in protein ingredients throughout the years have made it easier to incorporate certain raw materials into processed meats. The utilization of non-traditional raw materials must be considered to maintain a balance in the production and sale of processed meat products.

Non-traditional raw materials include blood plasma, pork skin and poultry skin. Blood plasma, which is extracted from the blood by a separator at the harvesting facilities, can be used in processed meat formulations. Pork and poultry skin were first introduced and used in a raw or cooked form as part of processed meat formulations. Currently skin can be processed into a granule form and is dehydrated during processing. The collagens produced are commonly referred to as functional meat proteins.

Blood proteins have been used for many years as a functional and nutritional food ingredient in many countries of the world. Blood collected from livestock in accordance with United States Department of Agriculture (USDA) regulations (USDA 2002) may be used in non-specific meat products intended for human consumption. Blood must be processed from a liquid form to a shelf-stable powder form which is light tan in color. Blood plasma has a protein content of approximately 70 percent and due to the color and functional properties, blood plasma is the portion of blood that is of greatest interest.

Many researchers have studied the use of blood plasma in meat systems. Caldironi and Ockermann (1982) reported that a bologna sausage produced with 10 percent of the meat replaced by plasma and globin protein was acceptable to a sensory panel. Murmann

and Wenzel (1986) reported the production of frankfurter-type sausage products in which blood plasma concentrate was used to replace ice and/or lean meat. The authors reported an increase in pH with increasing plasma concentrate content. The addition of blood plasma reduced firmness of the final product and sensory deviations from the control were noticeable at a blood plasma concentrate content of 6.75 percent.

Bovine plasma protein was utilized at three levels (1.5, 2.5, and 3.5 percent) in ground beef patties to research texture, color, and sensory characteristics (Guzmań and others 1995). The lightness (L* values) of uncooked beef patties generally decreased with increased blood plasma. Cooking losses were lower ($P<0.05$) for beef patties with 3.5 percent blood plasma due to the gelling properties that have the ability to entrap moisture and fat released from the meat during heating. The a* values of cooked treatment patties were not different ($P<0.05$) from those of cooked controls. The L* values and b* values generally decreased as the blood plasma content increased.

Cofrades and others (2000) researched the effect of plasma protein and soy fiber content on bologna sausage properties. The authors determined that higher soy fiber and plasma contents favored the formation of harder, chewier structures with improved fat and water binding properties. Overall, plasma protein influenced binding and textural properties more than soy fiber. Blood plasma has been shown to have good water binding properties, but its use as a lean meat replacement for processed meat products is limited by the reduction in firmness.

The skin from carcasses that have been previously inspected by the USDA have proven to be an effective raw material to be further processed into functional collagens for use in the production of processed meat products. As the raw material (skin) enters the processing facility, it is further inspected by USDA inspectors.

Researchers have studied the use of skin in raw or cooked form. Sadowska and others (1980) and Sadowska (1987) utilized varying levels (5, 15, 20, or 25 percent) of raw and cooked (100 °C for 0-90 minutes) pork skin collagen to examine the rheological properties of sausage batters and cooked sausage, respectively. It was reported that replacing 20 percent of the meat protein with pork skin collagen decreased batter viscosity and cooked sausage elasticity. Incorporation of cooked skin (15 percent of the total protein) resulted in batter with higher viscosity and higher cooked sausage elasticity when compared to batter or cooked sausage without pork skin collagen. The authors concluded that the addition of greater than 2.5 percent pork skin collagen would result in altered cooked sausage texture and appearance. Puolanne and Ruusunen (1981) hypothesized that connective tissue may be important for the water binding capacity and firmness of cold sausage.

Quint and others (1987) produced a loaf product that contained flaked pork skin and water that was pre-emulsified by passing it through an emulsion mill. The authors determined that the incorporation of the pre-emulsion improved bind of the emulsion and increased firmness, redness (a value), and yellowness (b value) colors of the loaf product. Delmore and Mandigo (1994) also added flaked pork skin sinew to low-fat, high-water added frankfurters at varying levels (0, 10, 20 percent of the formulation). Cooking yield, texture, and purge of the frankfurters were not altered by replacement levels of up to 20 percent pork connective tissue. There was no difference in juiciness, flavor, texture, or overall acceptability detected by consumer sensory panelists between frankfurters containing 0 to 10 percent pork sinew.

Osburn and others (1997) produced gels from flaked pork skin with varied amounts of added water (100, 200, 300, 400, 500, 600 percent). These pork skin gels were utilized

in reduced-fat bologna at levels of 10-30 percent addition. The greatest purge for any bologna occurred with the 600 percent added water, 30 percent addition treatment. Sensory panel analysis revealed that juiciness scores increased as added water and percent gel addition increased. The overall acceptability of the pork bologna with connective tissue tended to increase as added gel and added water increased. The authors concluded that the incorporation of pork connective tissue gels varied the functional, textural, and sensory attributes in reduced-fat bologna (Osburn and others 1997).

More recently, Prabhu and Doerscher (2000) utilized processed (dehydrated) pork skin collagen in reduced-fat frankfurters to increase cooking yield and decrease purge in the final product. The authors also researched the effect of pork collagen in fat-free pork sausage formulations. The results indicated increased cooked yields with a reduction in cooked diameter shrink. The authors concluded that the addition of 1 percent hydrated collagen at a 1:4 ratio is a cost-effective (for example improved yields), functional ingredient that can improve the quality (for example texture improvement) of various meat products.

Baker and others (1968) studied the effect of chicken skin on the eating quality of chicken frankfurters. Skin levels in the range of 5 to 20 percent had little effect on the tenderness or juiciness of the finished product. The authors concluded that the addition of chicken skin did not make the finished frankfurters mushy; that, on the contrary, at the levels above 20 percent, the frankfurters were evaluated as more firm and chewy. Schnell and others (1973) also studied the effect of chicken skin on the eating quality of chicken frankfurters. The authors reported that the presence of chicken skin in the formulation increased tenderness and viscosity. It was again concluded that chicken skin did not adversely affect the overall acceptability of the finished product. However, there was a

significant ($P<0.05$) decrease in product acceptability when 30 percent chicken skin was added to the frankfurters.

Acton and Dick (1978) produced poultry loaves with turkey thigh meat and proportions of turkey skin ranging from 10 to 50 percent of the formulation. The authors reported significant ($P<0.05$) increases in cooking loss as the skin content of the loaves increased, which was due primarily to the shift in moisture and fat ratios of the formulations. Similar shear forces for all treatments were reported and redness values decreased as the turkey skin levels increased.

Bonifer and others (1996) evaluated the functional properties of washed chicken skin in a bologna product at the levels of 0, 10, and 20 percent. Chicken skin content did not affect fat or gel-water losses and lowered solids loss when compared to bologna with no chicken skin ($P<0.05$). Kramer Shear peak force was not significantly different ($P<0.05$) for bologna at each treatment level. The authors also reported that the addition of chicken skin did not affect compression measurements of hardness, springiness, cohesiveness, and chewiness when compared to bologna with 0 percent skin. The addition of the chicken skin resulted in a lighter, less red, and less yellow product according to HunterLab color analysis ($P<0.05$). Consumer panelists rated bologna with 10% chicken skin highest in texture, flavor and appearance acceptability ($P<0.05$).

Osburn and Mandigo (1998) researched reduced-fat bologna manufactured with poultry skin connective tissue. The authors manufactured chicken skin connective tissue gels with added water (100, 200, and 300 percent) and then incorporated varying levels (10 to 30 percent) of the gels into reduced-fat bologna formulations. All bologna treatments exhibited acceptable sensory attributes. The authors concluded that it was feasible to use

added water-chicken skin connective tissue gels as a texture modifying agent in reduced-fat comminuted meat products.

Prabhu (2003) reported that functional collagen proteins from chicken and turkey skins can bind three to four times their weight in water and can form a firm elastic "cold" gel producing texture characteristics that are similar to meat. Prabhu stated that this gel functions as a matrix stabilizer of finely comminuted and coarse-ground meat products such as frankfurters or sausages. The author suggested that collagens immobilize free water and prevent moisture loss during heat processing as well as improve texture while reducing purge loss.

Poultry collagens have been researched in numerous processed meat products such as chicken nuggets, breakfast sausage, coarse-ground smoked sausages, and fresh ground meat products (for example turkey burger). Prabhu (2003) reported controlled purge and texture of turkey smoked sausages when 5 percent of the turkey thigh meat was replaced with 1 percent turkey collagen and 4 percent water. Furthermore, a cost savings of 3.1 percent was recognized. It was also reported that poultry collagens could be incorporated by either tumbling or massaging the collagen into whole muscle meat products such as chicken breast and chicken wings. The overall results of adding 1 percent to 2 percent poultry collagen to replace a portion of the lean meat block are numerous. A substantial cost savings could be achieved without a reduction in eating quality characteristics of the final processed meat product.

Much of the research in the use of different proteins in processed meat products has examined the effect of extenders/binders at a single replacement level. In the United States, meat processors have been using functional non-meat proteins in a finely comminuted meat emulsion systems at levels of 1-3.5 percent on a dry weight basis. When

rehydrated, these extenders replace 3-15 percent of the meat component in a formulation (Randall and others 1976). Because of higher meat prices and the availability of relatively low cost non-traditional meat proteins, the potential exists to utilize these proteins at appropriate levels as direct replacement of meat proteins.

Using a model emulsion system or an actual frankfurter emulsion formulation, the processing and quality characteristics of products utilizing non-traditional meat products can be measured. A systematic study of the effect of these functional meat proteins in a model emulsion system and the subsequent correlation to a frankfurter has generally been neglected. Although a functional meat protein may impart desirable characteristics in a model emulsion system, the final products (that is frankfurters) may have unacceptable processing or finished product characteristics.

Model systems are generally utilized to determine the functionality or interaction of proteins in dilute myosin, actomyosin, or myofibril solutions and gels. However, processed muscle foods represent a more complex system which, in addition to myofibrillar protein, contains sarcoplasmic and stromal proteins as well as various lipids minerals, sugars, and other additives. Hence, considerable deviations could exist between model emulsion systems and processed meat production scenarios.

Townsend and others (1968) developed a method in which a basic sausage raw emulsion was produced and placed in a hand stuffer and stuffed into a 7/8 x 4 inch polycarbonate tube. The tubes were subsequently heat processed in a hot water bath (48.8 °C) and the temperature was intermediately raised until an internal temperature of 68.8 °C was achieved. The liquid released during cooking was decanted into a 15 ml tube and the total volume of liquid, fat, gel-water, and proteinaceous solids were measured. Other final

product characteristics (that is internal color and texture) were not measured, nor subsequently compared to commercial produced frankfurters utilizing the same formulation.

The meat processing industry is constantly seeking ways to utilize more of the meat animal. The use of non-skeletal tissues goes a long way towards satisfying needs such as cost containment, raw material balance, and final product quality characteristics. Fundamentally, meat processors must do more to maintain product yields and quality characteristics while reducing the costs and utilization of typical skeletal muscle proteins. This research was conducted with two objectives. The first objective was to determine if characteristics of cooked emulsions produced in a model system could be significantly ($P<0.05$) correlated to characteristics of frankfurters produced in a commercial production scenario. The second objective was to determine the effect of replacing the lean component of a frankfurter formulation with various protein ingredients and test the similarity between the control frankfurter and the treatments.

Materials and Methods

Model Emulsion System

Preparing the Meat Block

The lean pork source (ham *semimembranosus* muscles) was sorted on a subjective color measurement by Swift and Company personnel (Marshalltown, IA), using the National Pork Producers Council color standards (1999), in an attempt to decrease variability in the raw materials used with this phase of the project. The lean pork was trimmed free of all visible fat, vacuum packaged in 1.8-2.3 kgs bags, and shipped fresh to the Iowa State University Meat Laboratory. The lean pork was subsequently frozen in the blast freezer (-34 °C) and moved the next day into another freezer (-28 °C).

Prior to processing, the lean pork was tempered to 1 °C in a cooler (2 °C) for initial grinding. The lean was crust frozen in the blast freezer to aid in the grinding process and maintain the temperature at -1 °C.

The lean pork was ground (Biro grinder, Model 822, Marblehead, OH) through a 0.9525 cm grinder plate. A 5.90 kg sample was taken to determine the fat content using an Anyl Ray Fat Analyzer (Kartrig Pak, Model 316-48, Davenport, IA). The pork was then batched into individual treatments according to the required weight, packaged in vacuum bags (B540 17.8 x 30.5 cm, Cryovac Division, W.R. Grace & Co., Duncan, SC), and sealed (with vacuum) using a Multivac double chamber packaging machine (Model AG800, Kansas City, MO). Packaging film had an O_2 transmission rate of 3-6 cc/m^2/24 hr at 1 atm, 4.4 °C, and 0% relative humidity, and a vapor transmission rate of 0.5-0.6 g/645 cm^2/24hr and 100% relative humidity. The meat was then placed into the cooler (0 °C) until further processing the next day.

Preparing the Pork Fat

The source of the pork fat was pork backfat and was obtained from the Iowa State University Meat Laboratory. The pork fat was tempered in a cooler before processing. The pork fat was inspected, trimmed free of any visible lean, cut into strips and crust frozen before initial grinding to ensure the temperature was at -1 °C. The pork fat was ground through a 0.9525 cm grinder plate. A 5.90 kg sample was taken to determine the fat content using an Anyl Ray Fat Analyzer. The pork fat was then ground through a 0.3175 cm grinder plate. The pork fat was batched into the required weight increments for each treatment, placed on a metal tray, and put into the cooler (0 °C/32 °F) for further processing.

Developing the Model System Base Formulations

The meat block formulation was set at 32.5 percent fat content to establish a target fat content of 27.5 percent in the finished product. The formulations (Table 4.1) for the model system consisted of lean pork (ham *semimembranosus*), pork fat (pork backfat), ice, water, salt, and the treatment ingredient. The amount of salt varied between treatments to maintain a constant salt concentration based on the meat block weight.

Making the Emulsion

One day prior to processing, a bucket of ice water was placed in the cooler to equilibrate to approximately 0.5 °C. Model emulsions were produced using methods developed by Townsend and others (1968). The lean pork was chopped (Stephan chopper, Model 718.270.03, Stephan Food Processing Technology, Columbus, OH) with the salt and half of the ice/water (and treatment addition with the appropriate amount of water per treatment, if required) with a vacuum at 2100 rpm until 3 °C was achieved. The sides of the chopper bowl were scraped randomly with a plastic scraper attached internally to the chopper. The initial temperature and final temperature were measured by an internal temperature probe in the chopper. The initial temperature, final temperature, and total time required to achieve initial chop temperature were recorded.

After initial temperature was reached, the chopper was turned off, the chopper lid was removed, and the sides of the bowl were scraped with a rubber spatula. The fat and the rest of the ice/water were added and chopped under vacuum until the temperature reached 14 °C. The initial temperature, final temperature, and total time were recorded. The thermometer probe was disconnected from the chopping bowl and the thermometer probe connection was covered with a plastic cap. A scraper was used to remove any extra meat on the sides of the bowl that was not chopped with the emulsion. The emulsion was

removed from the chopping bowl and placed into a labeled vacuum bag (B540 17.8 x 30.5 cm). The emulsion was then vacuum packaged (with vacuum) and placed in the cooler until stuffed.

Procedures between the Treatments

The chopping bowl was rinsed with warm water and then ice was placed in the bowl to decrease the temperature of the bowl while rinsing the other equipment. The rubber spatula, plastic scraper, and blades were also rinsed with warm water. The ice was removed from the chopping bowl and the chopping bowl was wiped dry with paper towels. The Stephan chopper was assembled and the thermometer cable was connected to the bowl.

Stuffing the Emulsion

The vacuum bag with the emulsion was placed into the stuffer (5 lb. Sausage Stuffer, The Sausage Maker, Buffalo, NY), the tip of the bag was pulled out and cut off with scissors.

50 ml Centrifuge Tubes

The centrifuge tubes were labeled, weighed, and recorded previously. The stuffing horn (3.175 cm) was then tightened onto the stuffer. Ten 50 ml centrifuge tubes were stuffed with approximately 40-45 grams of emulsion for each treatment. The centrifuge tubes were tapped on the table to compact the emulsion in the centrifuge tube and the weight was recorded (excluding the centrifuge cap). The centrifuge tubes were sealed with a plastic cap, placed in a rack, and placed into the cooler until enough samples were accumulated to thermal process.

Wierbicki Tubes

To determine emulsion stability, the Rongey method (Rongey 1965; Sebranek and others 2001) was used. The 3.175 cm stuffing horn was also used for stuffing the Wierbicki tubes. Two Wierbicki tubes were labeled, weighed, recorded, and stuffed with approximately 25 grams of emulsion for each treatment. The emulsion was stuffed by resting the stuffing horn on the glass disc and simultaneously turning the stuffer handle. Some pressure was applied on the emulsion so that it filled the tube without air pockets, while not forcing the emulsion past the glass disc. The Wierbicki tubes were reweighed to determine the actual sample weight. After stuffing, the Wierbicki tubes were placed into the cooler until eight Wierbicki tubes were accumulated for thermal processing.

Thermal Processing of the Emulsion

50 ml Centrifuge Tubes

The centrifuge tubes were thermal processed in a hot water bath (72 °C) for 30 minutes to achieve an internal temperature of 71 °C. Samples were then removed from the hot water bath. The water and aqueous fat were drained from the tubes and the cooked samples were rolled over a paper towel to remove any excess liquid. The cooked sample weight was recorded and the sample was placed back into the centrifuge tube. The yield of the samples was determined using the following equation:

$$\textit{Percent yield} = (\textit{cooked sample weight} / \textit{raw sample weight}) \times 100$$

The centrifuge tubes were then sealed with the plastic cap and placed into the cooler for further analysis.

Wierbicki Tubes

The Wierbicki tubes were thermal processed in a hot water bath (72 °C) for 30 minutes to achieve an internal temperature of 71 °C. The tubes were then removed from

the hot water bath and allowed to cool for 2-3 minutes. The tubes were then centrifuged at low speed (10,000 rpm) for 5 minutes. The tubes were removed from the centrifuge machine (Model 61, Chicago Surgical and Electrical Co. Chicago, IL) and the amounts of separated fat (top layer) and separated water (bottom layer) were read and recorded. The percent water separation and percent fat separation were determined by the following equations:

Percent water separation = (ml of water / sample weight) x 100

Percent fat separation = (ml of fat / sample weight) x 100

Percent total liquid separation = % water separation + % fat separation

pH Determination

pH was measured on each treatment. Raw emulsion and cooked pH were measured using a pH-STAR Pistol (SFK Technology, Denmark). Prior to the measurement, the pH-STAR Pistol was calibrated using the technical calibration solutions of pH 4.6 and pH 7. The calibration solutions were refrigerated as the pH was taken on refrigerated samples (2 °C). The identification number was recorded, the tip of the electrode was inserted into the sample, and the pH was recorded. The tip of the electrode was rinsed with distilled water between sample readings. For each treatment, measurements were made in duplicate.

Chemical Analysis (Fat, Moisture, and Protein)

Fat, moisture, and protein determinations were performed for each replication using the Soxhlet apparatus (hexane extraction) (AOAC 1990a), gravity oven drying (AOAC 1990b), and combustion method (AOAC 1993), respectively. For each treatment, measurements were made in duplicate. Ash was determined by adding the fat, moisture, and protein values together and subtracting the total from 100.

Color Analysis

Instrumental color analysis was conducted to determine internal color. Color readings were taken using a HunterLab Labscan instrument (Model LS, 1500, Reston, VA). Color readings evaluated CIE L* (lightness), a* (redness/greenness) and b* (yellowness/blueness). A port size of 1.27 cm was used with the A illuminant light source and a 10° standard observer. Calibrations were conducted after covering the calibration plates with Saran film. Tube samples were sliced in half longitudinally. The samples were then covered with Saran film and readings were taken through the Saran film. Two readings were taken per sample (that is tube or frankfurter) and three samples were measured, giving a total of six measurements per treatment.

Texture Analysis

Puncture Test

The puncture test was selected because the results could be directly compared even though the samples may have slightly different diameters. Texture was determined using the TA.XT2i Texture Analyzer (Texture Technologies Corp., Scarsdale, NY). Sample identification numbers were entered into the computer and a 3 mm diameter stainless steel puncture probe (TA-52) was used.

The 3 mm probe was programmed to penetrate 12 mm into each sample after the TA.XT2i detects the sample's surface at 12 grams of resistance. The penetration was 1.5 mm/second. The pre-test speed was 3.0 mm/second and the post-test speed was 10.0 mm/second. Samples were tested at room temperature (one hour after being removed from refrigeration) to ensure consistency between treatments. No tests were conducted within the last 1.27 cm of the end of the sample.

Samples were measured for penetration peak force and average interior firmness. The peak force was determined to be the force required to break the outer surface or skin (exterior firmness) of the sample. The average interior firmness was the force required to penetrate each sample between 6.0 mm and 10.0 mm peak force of penetration.

The 50 ml centrifuge samples were analyzed using the puncture test. The frankfurter-skin off macro analysis was performed on the data recorded by the TA.XT2i texture analyzer. The frankfurter-skin off macro analysis recorded values that were more representative of the sample used due to the lack of "skin" formation on the 50 ml centrifuge tube samples. For each treatment, three readings were taken per sample and two samples were measured giving a total of six measurements per treatment.

Two-Compression Test

The TA.XT2i Texture Analyzer was also used to determine the texture profile analysis of samples by a two-compression test illustrated by Bourne (1978) and Steffe (1996). The sample was cut to yield a 2.54 cm cylinder. The TA.XT2i Texture Analyzer was calibrated with a 5 kg weight and Texture Expert software was used. The test was performed at 3.3 mm per second with a 12.7 mm compression (50 percent) on one sample and an 18 mm compression (72%) on a second sample. Two compression quantities (50% and 72%) were used. A 5 gm change in force was set to signal that the sample was present. A TA-4 (40 mm cylinder) was used and the computer was set to acquire 200 points per second during the experiment.

The 50 ml centrifuge tube samples were measured for cohesiveness, gumminess, chewiness, springiness, hardness 1 (first bite), and hardness 2 (second bite). One reading was taken per sample and the experiment was conducted in triplicate.

Frankfurter Emulsion System

Preparing the Meat Block

The lean pork source (picnic cushion meat - 88/12) was purchased from Iowa Packing Company (Des Moines, IA). After receiving the pork trim, it was subsequently frozen in the blast freezer (-34 °C) and moved the next day into another freezer (-28 °C). Prior to processing, the lean pork was tempered to 1 °C in a cooler at 2 °C for initial grinding. Grinding took place one day prior to emulsion production. The lean was crust frozen in the blast freezer to aid in the grinding process and maintain the temperature at -1 °C.

The lean pork was ground (Biro grinder, Model 7552, Marblehead, OH) through a 1.27 cm grinder plate. A 5.90 kg sample was randomly taken to determine the exact lean and fat content using an Anyl Ray Fat Analyzer. The lean was then batched into individual treatments according to the required weight in meat lugs. The meat was then placed into the cooler (0 °C) until further processing the next day.

Preparing the Pork Trim 50/50

The fat pork source (pork trim - 50/50) was also purchased from Iowa Packing Company (Des Moines, IA). After receiving the pork trim, it was subsequently frozen in the blast freezer (-34 °C) and moved the next day into another freezer (-28 °C). Prior to processing, the pork trim was tempered to 1 °C in a cooler (2 °C) for initial grinding. Grinding took place one day prior to emulsion production. The pork trim was crust frozen in the blast freezer to aid in the grinding process and maintain the temperature at (-1 °C).

The pork trim 50/50 was ground through a 1.27 cm grinder plate. A 5.90 kg sample was randomly taken to determine the exact lean and fat content using an Anyl Ray Fat Analyzer. The pork trim was then batched into individual treatments according to the

required weight in meat lugs. The meat was then placed into the cooler (0 °C) until further processing the next day.

Developing the Frankfurter Base Formulations

The meat block formulation was set at 32.5 percent fat content to establish a target fat content of 27.5 percent in the finished product. The formulations (Table 4.2) for the frankfurters consisted of lean pork (picnic cushion meat – 88/12), pork trim (50/50), ice, water, spice, salt, sodium phosphate, sodium erythorbate, curing salt (6.25 percent sodium nitrite), and the treatment ingredient. The specific treatment ingredients used were chicken collagen, and turkey collagen.

Making the Emulsion

One day prior to processing, a container of ice water was placed in the cooler to equilibrate to approximately 0.5 °C. Emulsions were produced using methods described by Rust (1987). The picnic cushion trim was chopped (Kramer-Grebe bowl chopper, Model VSM65, Wallau/Lahn, Germany) with the salt, curing salt, and half of the ice/water (and treatment addition with the appropriate amount of water per treatment, if required) with a vacuum until 3 °C was achieved. The sides of the chopper bowl were scraped randomly with a plastic scraper.

After the initial temperature was reached, the chopper blades were turned to a low speed and the bowl was left on low to incorporate the remaining ingredients. The 50/50 pork trim, spices, sodium erythorbate, and the sodium phosphate, which was diluted in the remaining ice/water, were added to the bowl chopper and chopped under vacuum until the temperature reached 14 °C. The emulsion was removed from the chopper and placed into a labeled meat lug. A portion of the emulsion (approximately 1.8 kg) was placed in a vacuum bag (Cryovac B540 17.8 x 30.5 cm). The emulsion was then vacuum packaged (with

vacuum) using a Multivac double chamber-packaging machine and placed in the cooler until it was stuffed.

Procedures between the Treatments

The chopping bowl was rinsed with cold water and dried with paper towels. The plastic scraper and blades were also rinsed with cold water.

Stuffing the Emulsion

The vacuum bag with the emulsion was placed into the stuffer (5 lb. sausage stuffer), the tip of the bag was pulled out and cut off with scissors.

Wierbicki Tubes

To determine emulsion stability, the Rongey method (Rongey 1965; Sebranek and others 2001) was used. The 3.175 cm stuffing horn was tightened onto the stuffer. Two Wierbicki tubes were labeled, weighed, recorded and stuffed with approximately 25 grams of emulsion for each treatment. The emulsion was stuffed by resting the stuffing horn on the glass disc and simultaneously turning the stuffer handle. Some pressure was applied on the emulsion so that it filled the tube without air pockets, while not forcing the emulsion past the glass disc. The Wierbicki tubes were reweighed to determine the actual sample weight. After stuffing, the Wierbicki tubes were placed into the cooler until eight Wierbicki tubes were accumulated for thermal processing.

Cellulose Casings

The majority of the emulsion was placed into the stuffer (Risco stuffer, Model RS 4003-165, Stoughton, MA) and stuffed into a 21-22 mm cellulose casing (Devro-Teepak Wienie-Pak RP 24/10, Westchester, IL), linking the casing to yield approximately eight frankfurters per pound of finished product. The treatments were labeled and drenched with liquid smoke (Supreme Poly liquid smoke, Red Arrow Products Company, Manitowoc, WI)

to develop a uniform smoke color on the finished product. The liquid smoke solution consisted of 20 percent Supreme Poly and 80 percent cold water. The frankfurters were drenched for 90 seconds. The raw product was subsequently weighed and recorded to determine yields. The treatments were then randomly placed on a smokehouse truck. After four treatments were placed on the smokehouse truck, it was moved into the smokehouse for thermal processing. Between each treatment the stuffer was disassembled and rinsed with warm water.

Thermal Processing of the Emulsion

Wierbicki Tubes

The Wierbicki tubes were thermal processed in a hot water bath (72 °C) for 30 minutes to achieve an internal temperature of 71 °C. The tubes were then removed from the hot water bath and allowed to cool for 2-3 minutes. The tubes were then centrifuged at low speed (10,000 rpm) for 5 minutes. The tubes were removed from the centrifuge machine and the amounts of separated fat (top layer) and separated water (bottom layer) were read and recorded. The percent water separation and percent fat separation were determined by the following equations:

Percent water separation = (ml of water / sample weight) x 100

Percent fat separation = (ml of fat / sample weight) x 100

Percent total liquid separation = % water separation + % fat separation

Cellulose Casings

Thermal processing of the cellulose casing samples (frankfurter samples) were done using an Alkar thermal processing unit (Model MT EVD RSE 4, Alkar Engineering Corp., Lodi, WI). The thermal processing schedule accommodated the drenching of the raw product to

develop exterior smoke color. The final internal temperature of the product was brought to 71 °C using the cooking schedule in Table 4.3.

The smoke house truck was then covered with a plastic combo liner and moved into the finished product cooler (2 °C). The following day, the cellulose casing samples were reweighed to determine the cold yield using the following equation:

Percent smokehouse yield = (cold cooked weight / raw weight) x 100

A Townsend Engineering peeler (Model 260, Townsend Engineering, Des Moines, IA) was used to peel the frankfurters prior to packaging. The treatments were then packaged in vacuum bags (Cryovac B540 17.8 x 30.5 cm), vacuum packaged, and heat shrunk. The frankfurters were then boxed, returned to the cooler (2 °C) and held for further analysis.

Chemical Analysis (Fat, Moisture, and Protein)

Fat, moisture, and protein determinations were performed for each replication using the Soxhlet apparatus (hexane extraction) (AOAC 1990a), gravity oven drying (AOAC 1990b), and combustion method (AOAC 1993), respectively. For each treatment, measurements were made in duplicate. Ash was determined by adding the fat, moisture, and protein values together and subtracting the total from 100.

Color Analysis

Instrumental color analysis was conducted to determine internal color. Color readings were taken using a HunterLab Labscan instrument. Color readings evaluated CIE L* (lightness), a* (redness/greenness) and b* (yellowness/blueness). A port size of 1.27 cm was used with the A illuminant light source and a 10° standard observer. Calibrations were conducted after covering the calibration plates with Saran film. Tube samples and frankfurters were sliced in half longitudinally. The samples were then covered with Saran film and readings were taken through the Saran film. Two readings were taken per sample

(that is tube or frankfurter) and three samples were measured, giving a total of six measurements per treatment.

Purge Analysis

Purge loss was measured on duplicate samples. The weight of the packages (6 frankfurters/package) was taken on day 1 (one day after packaging), day 7, day 14, day 21, and day 28 for each replication. On the appropriate day, the packages (containing the frankfurters) were weighed, opened, drained, and the packaging material was blotted dry. The frankfurter and packaging material were then reweighed to determine the weekly purge loss. Purge loss was calculated by the following equation:

Percent = 100 - ((frankfurter weight + dried package weight) / initial package weight) x 100
purge loss

Texture Analysis

Puncture Test

The puncture test was selected because it measures the force required to push a punch or probe into a food. Texture was determined using the TA.XT2i Texture Analyzer. The texture analyzer was calibrated using a 5 kg weight prior to texture measurement. Sample identification numbers were entered into the computer and a 3 mm diameter stainless steel puncture probe (TA-52) was used.

The 3 mm probe was programmed to penetrate 12 mm into each sample after the TA.XT2i detects the sample's surface at 12 grams of resistance. The penetration was 1.5 mm/second. The pre-test speed was 3.0 mm/second and the post-test speed was 10.0 mm/second. Samples were tested at room temperature (one hour after being removed from refrigeration) to ensure consistency between treatments. No tests were conducted within the last 1.27 cm of the end of the sample.

Samples were measured for penetration peak force and average interior firmness. The peak force was determined to be the force required to break the outer surface or skin (exterior firmness) of the sample. The average interior firmness was the force required to penetrate each sample between 6.0 mm and 10.0 mm peak force of penetration. For each treatment, two readings were taken per sample and three samples were measured giving a total of six measurements per treatment.

Two-Compression Test

The TA.XT2i Texture Analyzer was also used to determine the texture profile analysis of samples by a two-compression test illustrated by Bourne (1978) and Steffe (1996). The sample was cut to yield a 2.54 cm cylinder. The TA.XT2i Texture Analyzer was calibrated with a 5 kg weight and Texture Expert software was used. The test was performed at 3.3 mm per second with a 12.7 mm compression (50 percent) on one sample and an 18 mm compression (72 percent) on a second sample. Two compression quantities (50 percent and 72 percent) were used. A 5 gm change in force was set to signal that the sample was present. A TA-4 (40 mm cylinder) was used and the computer was set to acquire 200 points per second during the experiment. Samples were measured for cohesiveness, chewiness, springiness, hardness (first bite). One reading was taken per sample and the experiment was conducted in triplicate.

Sensory Evaluation of Texture

The appropriate forms were completed and submitted to the Iowa State University Institutional Review Board prior to the training of the sensory panels. Panelists were recruited from the faculty, staff, and students in the Department of Food Science and Human Nutrition at Iowa State University. A ten-member trained sensory panel was used to evaluate the texture characteristics of the treatments. Three one-hour training sessions

were held at which time panelists were familiarized with the attributes to be evaluated, the techniques to be used during the evaluation process, and the computer software scoring system. Panelists were trained by using commercial products selected to exhibit a range of the intensity of the attributes being evaluated. The sensory evaluation utilized several descriptive terms the panelist were trained to use during initial panel preparation. These descriptive terms for each attribute are outlined in Table 4.4, and the scoring scale sheet is outlined in Figure 4.1.

Attributes were measured using a line scale (numerical value of 15 units) for each of the parameters with descriptive anchors indented 0.5 units from each end of the line. Data was collected using a computerized sensory system (COMPUSENSE five, V4.0, Compusense, Inc., Guelph, Ontario, Canada). Frankfurters were placed in a two-quart saucepan containing water that had been brought to a boil. The pan was then covered and removed from the heat and held for seven minutes. The ends of the heated frankfurters were discarded and the remaining portion was cut into 1.3 cm long pieces. Each panelist received pieces from a single frankfurter in a covered four-ounce polyfoam container labeled with a random three-digit code. Samples were served at room temperature. Frankfurters were evaluated in three sessions and for each session, cooking and cutting orders were randomized (American Society for Testing and Materials 1988).

Testing was conducted in partitioned booths under fluorescent lighting conditions. Panelists were provided with water and saltine-type crackers (unsalted tops) and allowed to re-taste. For several of the attributes, a sample with a designated value was available if the panelist wished to use it as a reference during the test. The sample presentation order was randomized for each panelist.

Experimental Design and Data Analysis

Each of the six treatments (control or one of five replacement proteins) was replicated three times in a randomized complete block design. Treatment means and standard errors were computed for all responses, after adjusting for differences between blocks. Computations were done using SAS, version 8.1 (SAS 2001).

The classical null hypotheses for 1-way ANOVA (equality of all treatment means) or pair-wise comparisons (no difference between a pair of treatments) are not appropriate when the intent is to show that the treatment has no effect (Dixon 1998). Accepting the null hypothesis (of no difference) does not prove that the treatment has no effect. A non-significant statistical result may arise even if the treatment has a large effect if the uncertainty (e.g. standard error of the mean) is large. A second issue is the confusion of statistical significance with biological significance (Dixon 1998). A treatment that is very close to zero may be 'statistically significant' if the standard error of the mean is very small. We use statistical equivalence tests to evaluate if the effect of a treatment is "equivalent to zero" (Dixon 1998).

A statistical equivalence test reverses the usual null and alternative hypotheses. Consider testing whether a specific response for frankfurters with 1% gelling plasma is equivalent to that from the control treatment. The null hypothesis for an equivalence test is that the difference between the two treatments is large. To illustrate the approach, assume that the mean response for the control frankfurters is 5.6. If the pH for the 1% gelling plasma treatment was smaller than 5.50 or larger than 5.75, the difference between the two treatments might be considered large. The alternative hypothesis is that the difference is close to zero. The values of 5.50 and 5.75 define the equivalence region, the set of differences that are considered equivalent to zero.

Because the many responses considered here have different units and magnitudes, it was easiest to specify the equivalence region as a proportion of the control mean for each response. In the evaluation of the effectiveness of generic drugs, the United States Food and Drug Administration (FDA) requires that generic drugs be within 20% of the name-brand drug (Chow and Liu 1992). We used tighter equivalence bounds in this study. A 90% equivalence region was used for all processing parameters (water and fat separation, proximate composition, interior color, and purge). For each response, the lower bound of the equivalence region was 0.9 times the control mean and the upper bound was 1.11 times the control mean. An 85% equivalence region was used for puncture and texture analysis data due to the sensitivity of the TA.XT2i texture analyzer and the sample-sample variability that is evident within each treatment. The equivalence ranges for responses measured in the centrifuge tube system are displayed in Table 4.5. The ranges for responses in the frankfurter system are displayed in Table 4.6.

Because the mean for the control treatment is estimated with variability, the statistical analysis is based on differences between treatment means and an equivalence region for the difference between treatments. To continue the example above, the equivalence region of (5.50, 5.75) for the treatment mean is equivalent to an equivalence region of (-0.10, 0.15) for the difference between the treatment and control means.

The two one-sided tests approach (Dixon 1998) was used to test the null hypothesis that the difference between treatment and control mean is outside the pre-specified equivalence range. The null hypotheses for the two one-sided tests are that the difference in means is larger than the lower bound of the equivalence region and that the difference is smaller than the upper bound. The treatment group is equivalent to the control group only if both one-sided tests are significant. All tests were done at $\alpha = 0.05$.

Data was also subjected to correlation tests to determine if the parameters measured (that is processing, color, texture puncture) in the model emulsion system correlate to the same parameters measured in the frankfurter system. Within the frankfurter experiment, texture, puncture, and sensory parameters were subjected to correlation tests in an attempt to correlate texture characteristics measured by the TA.XT2i texture analyzer to the results of the sensory analysis.

Results and Discussion

Yield, pH, Water Separation, and Fat Separation

The least squares means for centrifuge tube yield and frankfurter smokehouse yield are displayed in Table 4.7 and Table 4.8, respectively. Within both systems (that is model and frankfurter) all treatments were equivalent to the control ($P<0.05$). Cofrades and others (2000) reported that blood plasma has good water binding properties, while Prabhu and Doerscher (2000) reported increased cooking yields with the use of dehydrated pork skin collagen (Myogel/Myogel Plus) in reduced-fat frankfurters. Prabhu (2003) suggested that functional collagens from chicken and turkey skins prevent moisture loss during thermal processing. Due to the differences in sample preparation and cooking methods between the model and frankfurter systems, a large difference in yields was evident.

The least squares means for raw emulsion pH and cooked sample pH of samples produced by a modified Townsend (1968) method are displayed in Table 4.9. The pH measurements of both variables (that is raw emulsion and cooked sample) for the treatments were equivalent to the control ($P<0.05$). Although Murmann and Wenzel (1986) reported an increase in pH with increasing plasma concentrate content, our results reveal that at a 4 percent replacement level (1 percent gelling plasma:3 percent water) the

treatment samples were equivalent to the control. In general, the cooked emulsion pH was slightly higher than the raw emulsion pH. Due to minimal differences reported in the model emulsion system, pH was not measured on the raw emulsion or cooked samples in the frankfurter system

The least squares means for percentage water and fat separation of the emulsion produced in the model system are displayed in Table 4.10. The percent water separation of all treatments was not equivalent to the control ($P<0.05$). On the other hand, the water separation of the gelling plasma, Myogel Plus, and turkey collagen treatments were lower than the control. These results are consistent with reports from Cofrades and others (2000), Prabhu and Doerscher (2000), and Prabhu (2003). The percent fat separation of all of the treatments was not equivalent to the control ($P<0.05$).

The least squares means for percentage water and fat separation of the emulsion produced in the frankfurter system are displayed in Table 4.11. The percent water and fat separation of all of the treatments were not equivalent to the control ($P<0.05$). These results contradict suggestions made by Cofrades and others (2000), Prabhu and Doerscher (2000), and Prabhu (2003). These results are in agreement with previously discussed results from the model emulsion system. Although all treatments were not equivalent to the control ($P<0.05$), with the exception of the turkey collagen treatment, all treatments displayed less fat separation when compared to the control.

Overall the emulsion produced by the frankfurter system seemed to release more water and fat than the emulsion produced from the model system. These differences are most likely due to processing differences between the chopping systems. The model emulsion system used a small chopping system (Stephan chopper) while the frankfurter system used a large chopping system (Grebe bowl chopper).

Proximate Composition

The least squares means for the proximate analysis of the samples produced in the model emulsion and frankfurter systems are displayed in Table 4.12 and Table 4.13, respectively. All treatments within the model emulsion system were equivalent to the control ($P<0.05$) for all proximate analysis parameters (that is moisture, fat, protein, and ash). All frankfurter treatments had equivalent moisture and protein content when compared to the control ($P<0.05$). The Myogel treatment was the only treatment that displayed equivalent fat content to the control ($P<0.05$). Although the fat content of the remaining treatments were not equivalent to the control, they were lower than the control. All frankfurter treatments, did not display equivalent ash content when compared to the control ($P<0.05$), but minimal differences were observed.

In general, samples produced with the frankfurter system had a lower moisture content and a higher fat content than samples produced by the model emulsion system. Although 4 percent of the lean meat in the treatment formulations was replaced with 1 percent treatment ingredient and 3 percent water, moisture content was equivalent to the control ($P<0.05$) in both processing systems. Furthermore, in the model emulsion system the fat content of the treatments remained constant while in the frankfurter system the fat content of the treatments was lower than the control. The protein and ash content in both systems were similar.

Terrell and others (1979) reported no significant ($P>0.05$) difference in moisture, fat, protein and ash content in frankfurters extended with 1 percent plasma protein. Delmore and Mandigo (1994) utilized flaked pork sinew at varied levels in low-fat, high-water frankfurters an reported no significant ($P>0.05$) differences in proximate composition. Our poultry collagen treatment results are contrary to those reported from Acton and Dick

(1978). The authors reported that the use of poultry skin resulted in a higher fat content in the final product. This conclusion is not comparable to this study due to the differences between the poultry collagen utilized in the research projects. Acton and Dick (1978) used raw poultry skin whereas this study utilized processed poultry skins.

Color Analysis

The least squares means for the color analysis of the samples produced in the model emulsion and frankfurter system are displayed in Table 4.14 and Table 4.15, respectively. All treatments within the model emulsion system were equivalent to the control ($P<0.05$) for all color analysis parameters (that is CIE L*, a*, and b*). All frankfurter treatments had equivalent CIE L* values when compared to the control ($P<0.05$). With the exception of the Myogel Plus treatment, the CIE a* value for all treatments were equivalent to the control ($P<0.05$). All frankfurter treatments, excluding the turkey collagen treatment, had equivalent CIE b* values when compared to the control ($P<0.05$). The Myogel Plus treatment had a less red interior color when compared to the control. The turkey collagen treatment had a more yellow interior color when compared to the control. Overall, samples produced with the frankfurter system had a darker, less red interior color than samples produced by the model emulsion system. The CIE b* values in both systems were similar.

Although Guzmań and others (1995) reported significantly ($P>0.05$) lower L* and b* values as blood plasma content increased in beef patties, this scenario did not occur in the samples produced using the model or frankfurter system. Within the frankfurter system, the decreased a* value of the Myogel Plus treatment may be due to the removal of the lean portion of the formulation. The lean that was replaced with the treatment ingredient contains a majority of the color component (myoglobin). Therefore, removal of this component may tend to decrease the redness of the final product. This scenario was not

evident in the remaining treatments studied. The CIE b* values for the turkey collagen treatment resulted in a frankfurter with a more yellow interior color. These CIE b* results are contrary to the results of Bonifer and others (1996) who reported a less yellow product due to the addition of washed chicken skin.

Purge Analysis

The percentage of purge of all of the frankfurter treatments (Table 4.16) was not equivalent to the control at the 90 percent equivalence level ($P<0.05$). Most researchers have reported sufficient water holding capacity as a result of utilizing protein ingredients and our purge results are similar. Osburn and Mandigo (1998) reported the same trend of a slight increase in purge due to the addition of collagen. The results from the pork collagen treatments (Myogel and Myogel Plus) are consistent with reports from Prabhu and Doerscher (2000). The results from poultry collagen treatments contradict the report from Prabhu (2003).

Puncture Analysis

The least squares means for the puncture analysis of the samples produced in the model emulsion and frankfurter system are displayed in Table 4.17 and Table 4.18, respectively. The peak force values of all treatments within the model emulsion system, with the exception of the Myogel Plus treatment, were equivalent to the control ($P<0.05$), while the internal force values of all treatments were equivalent to the control ($P<0.05$). The peak force values of all frankfurter treatments were not equivalent to the control ($P<0.05$), while the internal force values of all frankfurter treatments were equivalent to the control ($P<0.05$).

In general, the samples produced by the model system had a much lower peak force and a lower internal force when compared to samples produced by the frankfurter system.

This phenomenon was most likely created by difference in sample manufacturing and thermal processing. Since the model emulsion was stuffed and cooked in 50 ml centrifuge tubes, an exterior "skin" was not produced. Therefore, peak force which measures the force required to break the exterior of the sample surface was much lower when compared to the frankfurter samples.

The interior force was lower in the samples produced in the model emulsion system due the method of thermal processing used (that is hot water bath). The thermal processing schedule of the smokehouse allows a gradual increase in internal temperature of the product, while the hot water bath was set at 72 °C. The hot water bath may not allow the proteins to bind together as well as the smokehouse. Furthermore, the sample produced in the model emulsion system had a higher moisture content and lower fat content than the samples produced in the frankfurter system. Therefore, this is likely to result in a final product with a softer interior texture. Claus and Hunt (1991) revealed that high water formulations of bologna required less force to fracture and were softer than bologna containing more fat.

Terrell and others (1979) reported that the use of plasma protein isolate at the 1 percent level in extended frankfurters increased ($P<0.05$) the strength of the outer skin of otherwise all-meat frankfurters and decreased the interior texture. Prabhu and Doerscher (2000) concluded that processed pork skin collagen in reduced frankfurters can improve the quality (that is texture improvement). Prabhu (2003) made the same suggestions with the use of functional collagens from chicken and turkey skin in frankfurter formulations. Although those inferences can not be made with our data, it was concluded that meat replacement protein treatments were equivalent to the control.

Texture Profile Analysis

The least squares means for the texture analysis of the samples produced in the model emulsion are displayed in Table 4.19. All treatments within the model emulsion system displayed equivalent cohesiveness and springiness when compared to the control ($P<0.05$). Within the chewiness texture parameter, the chicken collagen treatment was the only treatment that was not equivalent to the control ($P<0.05$). The gelling plasma treatment was the only treatment that revealed equivalent hardness to the control ($P<0.05$). All other treatments were not equivalent and were softer than the control ($P<0.05$). The hardness of the 50 ml centrifuge tube samples may have been affected by lack of "skin" formation on the exterior of the samples as discussed previously.

The least squares means for the texture analysis of the frankfurters produced in the frankfurter emulsion are displayed in Table 4.20. All treatments within the frankfurter system displayed equivalent cohesiveness and springiness when compared to the control ($P<0.05$). The chewiness and hardness of frankfurter treatments were not equivalent to the control ($P<0.05$).

Sadowska (1987) utilized varying levels (5, 15, 20, or 25 percent) of raw and cooked pork skin collagen to examine the rheological properties of cooked sausage and reported that the addition of greater than 2.5 percent pork skin collagen would result in altered cooked sausage texture. Although we utilized 1 percent pork collagen and 3 percent water as a 4 percent lean replacement, our TA.XT2i texture results were similar to the results reported by other researchers. The results from the poultry collagen treatments contradict results from Bonifer and others (1996) who reported that the addition of chicken skin did not affect the compression measurements of hardness, springiness, cohesiveness, and chewiness when compared to a control with no added skin.

Sensory Evaluation of Texture

The least squares means for the texture analysis of the frankfurters produced in the frankfurter emulsion are displayed in Table 4.21. All frankfurter treatments evaluated, with the exception of the chicken collagen treatment, displayed equivalent cohesiveness when compared to the control ($P<0.05$). The Myogel Plus treatment was the only treatment that displayed equivalent chewiness to the control ($P<0.05$). All treatments were not equivalent in springiness and hardness scores when compared to the control ($P<0.05$). The gelling plasma and Myogel Plus treatments displayed equivalent skin toughness to the control ($P<0.05$).

In general, all treatments displayed lower cohesiveness, chewiness, springiness, hardness, and skin toughness scores when compared to the control. Overall, our results are similar to the conclusions made by Osburn and others (1997). The incorporation or lean meat replacement with collagens creates varied sensory attributes. Although non-equivalence of specific sensory attributes was revealed by the replacement of the lean meat with the protein ingredient and water, this non-equivalence cannot be assumed to decrease consumer acceptability.

Correlation of Model Emulsion system and Frankfurter System

Although many correlations were attempted, only two parameters in the model emulsion system correlated to the frankfurter system. The interior CIE L* value of the model emulsion system centrifuge tube samples were significantly ($P<0.05$) negatively correlated (-0.54) to the interior CIE L* value of frankfurters. Within texture profile analysis, chewiness of the samples produced in the model emulsion system were significantly ($P<0.05$) correlated (0.52) with that of the frankfurters.

Correlation tests between the TA.XT2i texture analysis and sensory evaluation revealed a significant ($P<0.05$) correlation between parameters measured. Significant ($P<0.05$) correlations were observed between sensory skin toughness and puncture peak force (0.74) as well as sensory hardness and puncture internal force (0.70). These results suggest that the utilization of TA.XT2i puncture analysis is useful in determining two fundamental sensory characteristics. Furthermore, significant ($P<0.05$) correlations were revealed between sensory hardness and texture analysis hardness (0.60) as well as sensory chewiness and texture analysis chewiness (0.63). Meullenet and others (1994) reported that positive correlations between shear stress and hardness (0.76) as well as shear stress and chewiness (0.57). More recently, Yang and others (2001) reported significant correlations ($P<0.01$) between texture profile analysis attributes and sensory texture attributes.

Conclusions

This research has clarified the use of non-traditional raw materials such as blood plasma, pork skin, and poultry skin for meat emulsion-type products. While previous authors (Saffle and others 1964; Campbell and Kenney 1994) have reported undesirable characteristics with the use of collagens in processed meats, our research reveals that collagen can play an important role in comminuted meat products. The results of this study indicate that various protein ingredients can be used in frankfurters to replace a portion of the lean while maintaining processing, proximate composition, internal color, and various texture characteristics. Various specific sensory attributes were revealed to be non-equivalent to the control by the replacement of the lean meat with collagen and water. This non-equivalence should not be interpreted to mean decreased consumer acceptability.

Minimal correlations could be derived between the model emulsion system and the frankfurter system. These differences are most likely due to differences between the processing (chopping) systems and thermal processing utilized. Although correlations did not exist between the systems used, it should not be concluded that the model system is not useful. The model system may still be useful in a laboratory table-top product development scenario to test newly developed functional protein ingredients against functional protein ingredients that are currently being utilized. Significant correlations between puncture attributes, texture attributes, and sensory attributes were observed.

These results indicate that the hydration of 1 percent protein ingredient at a 1:3 ratio can be a cost-effective functional ingredient to replace 4 percent of the lean material utilized in processed meat formulations. The utilization of this processing technology will yield frankfurters equivalent to frankfurters with no lean replacement.

References

[A.O.A.C.] Association of Official Analytical Chemists. 1990a. Fat (crude) or ether extract in meat. In: Official Methods of Analysis, 15th ed. Arlington, VA: AOAC 960.39.

[A.O.A.C.] Association of Official Analytical Chemists. 1990b. Moisture in meat. In: Official Methods of Analysis, 15th ed. Arlington, VA: AOAC 950.46.

[A.O.A.C.] Association of Official Analytical Chemists. 1993. Crude protein in meat and meat products. In: Official Methods of Analysis, 15th ed 4th suppl. Arlington, VA: AOAC 992.15.

Acton JC, Dick RL. 1978. Effect of skin content on some properties of poultry meat loaves. Poultry Sci. 57(5):1255-1259.

Baker RC, Darfler JM, Vadehra DV. 1968. The effect of level of skin on the quality of chicken frankfurters. Poultry Sci. 47:1989-1996.

Bonifer LJ, Froning GW, Mandigo, RW, Cuppett SL, Meagher MM. 1996. Textural, color, and sensory properties of bologna contaning various levels of washed chicken skin. Poultry Sci. 75:1047-1055.

Caldironi HA, Ockermann HW. 1982. Incorporation of blood proteins into sausage. J. Food Sci. 47:405-408.

Chow SC, Liu JP. 1992. Design and Analysis of Bioavailability and Bioequivalence Studies. New York, NY: Marcel Dekker. P 71.

Claus JR, Hunt MC 1991. Low-fat, high-added water bologna formulated with texture-modifying ingredients. J. Food Sci. 56(3):643-652.

Cofrades S, Guerra MA, Carballo J, Fernández-Martín F, Jiménez Colmenero F. 2000. Plasma protein and soy fiber content effect on bologna sausage properties as influenced by fat level. J. Food Sci. 65(2):281-287.

Delmore RJ, Mandigo RW. 1994. Modified pork connective tissue for use in low-fat high added water frankfurters [abstract]. In: IFT Annual Meeting Book of Abstracts; 1994 June 25-29; Atlanta, GA. Chicago, IL.: Institute of Food Technologists. Abstract nr 47D-27.

Dixon PM. 1998. Assessing effect and no effect with equivalence tests. In: Newman MC, Strojan CL, editors. Risk Assessment: Logic and Measurement. Chelsea, MI: Ann Arbor Press. P 275-301.

Guzmań JC, McMillin KW, Bidner, TD, Dugas-Sims S, Godber JS. 1995. Texture, color and sensory characteristics of ground beef patties containing bovine blood proteins. J Food Sci. 60(4):657-660.

Meullenet JF, Chang HC, Carpenter JA, Resurreccion AV. 1994. Textural Properties of chicken frankfurters with added collagen fibers. J. Food Sci. 59(4): 729-733.

Murmann D, Wenzel S. 1986. The effect of blood plasma concentrate on the quality of frankfurter-type sausage. Fleischwirtsch. 66(7):1132.

Osburn WN, Mandigo RW. 1998. Reduced-fat bologna manufactured with poultry skin connective tissue gel. Poultry Sci. 77(10):1574-1584.

Osburn WN, Manidgo RW, Eskridge KM. 1997. Pork skin connective tissue gel utilization in reduced-fat bologna. J. Food Sci. 62(16):1176-1182.

Prabhu GR. 2003. Poultry collagen: Ingredients that combine flavor and functionality. Meat and Poultry. January: 68-75.

Prabhu GR, Doerscher DR. 2000. Collagen's new application. Meat and Poultry. April: 65-69.

Puolanne E, Ruusunen M. 1981. The properties of connective tissue membrane and pig skin as raw materials for cooked sausage. Meat Sci. 5(5):371-382.

Quint LN, Mandigo RW, Calkins CR. 1987. Use of pork skin pre-emulsions in a low-fat pork loaf product. Nebraska Swine Report. EC 87-219:22-24. Univ. of Nebraska, Lincoln, NE.

Randall CJ, Raymond DP, Voisey PW. 1976. Effect of various animal and vegetable protein materials on replacing the beef component in a meat emulsion system. Can. Inst. Food Sci. Technol. J. 9(4):216-221.

Rao PV. 1998. Single factor studies: Comparing means and determining sample sizes. In: Statistical Research Methods in the Life Sciences. Pacific Grove, CA: Brooks/Cole Publishing Co. P326-377.

Rongey EH. 1965. A simple objective test for sausage emulsion quality. Proc of Meat Ind. Res. Conf. American Meat Institute Foundation, Chicago, IL.

Rust RE. 1987. Sausage products. In: Price JF, Schweigert BS, editors. The Science of Meat and Meat Products, 3rd ed. Westport CT: Food and Nutrition Press, Inc. P 473-485.

Sadowska M. 1987. The effect of collagen on the stability and rheological properties of cooked sausages. In: Proc. European Meeting of Meat Research Workers, Helsinki, Finland. 2:274-276.

Sadowska M, Sikorski AE, Dobosz M. 1980. The influence of collagen on the rheological properties of meat homogenates. Lebensm. -Wiss. u. -Technol. 13(5):232-236.

SAS Institute, Inc. 2001. SAS user's guide, version 8.2. SAS Institute. Cary, NC.

Schnell PG, Nath KR, Darfler JM, Vadehra DV, Baker, RC. 1973. Physical and functional properties of mechanically deboned poultry meat as used in the manufacture of frankfurters. Poultry Sci. 52:1363-1369.

Sebranek JG, Lonergan SM, King-Brink M, Larson E. 2001. Emulsion evaluations and water holding capacity. In: Meat Science and Processing - 3rd ed. Zenda, WI: Peerage Press. P 134-146.

Terrell RN, Weinblatt, PJ, Smith GC, Carpenter ZL, Dill CW, Morgran RG. 1979. Plasma protein isolate effects on physical characteristics of all-meat extended frankfurters. J. Food Sci. 44:1041-1048.

Townsend WE, Witnauer LP, Riloff JA, Swift CE. 1968. Comminuted meat emulsions: Differential thermal analysis of fat transitions. Food Technol. 22(3):71-90.

United States Department of Agriculture. 2002. Saving of blood from livestock as an edible product. Code of Federal Regulations. Citation 9CFR310.20 (http://www.usda.gov). United States Department of Agriculture. Washington, DC.

Yang A, Keeton JT, Beilken SL, Trout GR. 2001. Evaluation of some binders and fat substitutes in low-fat frankfurters. J. Food Sci. 66(7):1039-1046.

Table 4.1. Formulations for pork emulsion from control and experimental samples formulated with a portion of lean replaced by various protein ingredients and produced by a modified Townsend (1968) method (Batch size: 1500 gms.).

	Control [a]	Treatments
		1% Treatment [b]
Ingredient	%	%
Pork Lean [c]	54.90	50.90
Pork Fat [d]	20.60	20.60
Ice	9.94	9.94
Water	9.94	9.94
Spice	2.11	2.11
Salt	1.82	1.83
Sodium Phosphate	0.45	0.45
Sodium Erythorbate	0.0413	0.0391
Curing Salt (6.25%) [e]	0.1885	0.1785
Treatment	0.00	1.00
Water for Treatment	0.00	3.00
	100.00	100.00

[a] Control = No lean meat replacement, same control was used for 1% and 2% treatments.
[b] 1% Treatment = 4% of the lean meat component in the emulsion formulation was replaced by 1% treatment ingredient and 3% water.
[c] Pork lean = Ham *semimembranosous* (90/10) purchased from Swift and Company (Marshalltown, IA) and trimmed practically free of all visible fat.
[d] Pork fat = Pork backfat purchased from Iowa State University Meat Laboratory (Ames, IA).
[e] Curing salt (6.25%) = Contains 6.25% sodium nitrite and 93.75% salt.

Table 4.2. Formulations for pork emulsion from control and experimental frankfurters formulated with a portion of lean replaced by various protein ingredients (Batch size: 75 lbs.).

	Control [a]	Treatments
		1% Treatment [b]
Ingredient	%	%
Pork Lean [c]	40.35	36.35
Pork Trim [d]	35.15	35.15
Ice	9.94	9.94
Water	9.94	9.94
Spice	2.11	2.11
Salt	1.82	1.83
Sodium Phosphate	0.45	0.45
Sodium Erythorbate	0.0413	0.0391
Curing Salt (6.25%) [e]	0.1885	0.1785
Treatment	0.00	1.00
Water for Treatment	0.00	3.00
	100.00	100.00

[a] Control = No lean meat replacement, same control was used for 1% and 2% treatments.
[b] 1% Treatment = 4% of the lean meat component in the emulsion formulation was replaced by 1% treatment ingredient and 3% water.
[c] Pork lean = Pork cushion (88/12) purchased from Iowa Packing Company (Des Moines, IA).
[d] Pork trim = Pork trim (50/50) purchased from Iowa State University Meat Laboratory (Ames, IA).
[e] Curing salt (6.25%) = Contains 6.25% sodium nitrite and 93.75% salt.

Table 4.3. Cooking schedule for frankfurters from control and experimental frankfurters formulated with a portion of lean replaced by various protein ingredients.

Step Type	Step Time	Dry Bulb (°C)	Wet Bulb (°C)	RH [a] (%)	IT [b] (°C)	Main Blower
Cook	00:10:00	43	38	70	-------	4
Cook	00:30:00	63	38	21	-------	10
Cook	00:30:00	63	38	21	-------	2
Cook	00:15:00	68	0	0	-------	7
Steam Cook	00:01:00	82	82	100	71	1
Cold Shower	00:15:00	10	10	0	-------	0

[a] RH = Relative humidity of the smokehouse.
[b] IT = Internal temperature of the frankfurter.

Table 4.4. Description of terms, techniques for texture evaluation, labels for anchors, commercial product references and texture reference value used for training sensory panelists as measured by using a line scale (numerical value of 15 units) with descriptive anchors for each of the texture parameters.

Term	Technique for Texture Evaluation	Label for 0	Label for 15	References and Values
Toughness of exterior	Place the sample between the incisors so that you will be able to bite through the skin. Bite down evenly, and evaluate the force to penetrate through the surface	Very soft	Very tough	Hormel Vienna Sausage Value = 1 Armour Stars Hot Dogs - Original Value = 11
Hardness	Place the sample between your molars as described above, bite down evenly, and evaluate the force to bite completely through the sample.	Very soft	Very hard	Gerber Graduate Meat Sticks Value = 1 Armour Stars Hot Dogs - Original Value = 10
Cohesiveness	Place the sample between your molars as described above, compress it fully and evaluate the degree to which the sample deforms before it ruptures. A sample with high cohesiveness will undergo much deformation before it ruptures. A sample with low cohesiveness ruptures with little deformation.	Not cohesive (little deformation before rupture)	Very cohesive (much deformation before rupture)	Jack Link's Original Beef Stick Value = 1

Term	Technique	Label for 0	Label for 15	Reference and Values
Springiness	Place the sample between your molars, with the cut edges adjacent to the surface of the molars. Compress partially without breaking, release, and evaluate the degree to which the sample returns to its original shape.	Not springy	Very springy	Gerber Graduate Meat Sticks Value = 1 Hormel Fat-Free Beef Hot Dogs Value = 10
Chewiness	The amount of chewing required to prepare the sample for swallowing.	Not chewy	Very chewy	Gerber Graduate Meat Sticks Value = 2 Armour Stars Hot Dogs - Original Value = 9
Juiciness	The progressive increase in the sensation of moisture in the mouth during chewing	Not juicy	Very juicy	No Reference

Table 4.5. Equivalence range determination for processing, proximate analysis, color, purge, puncture, and texture characteristics as measured on the least squares means from control and experimental samples formulated with a portion of lean replaced by various protein ingredients and produced by a modified Townsend (1968) method.

Production system	Measured variable	Equivalence (%) [a]	Equivalence range [a]
Model system	Yield	90	89.2 < 99.1 < 100
Model system	Raw emulsion pH	90	4.27 < 5.58 < 5.99
Model system	Cooked emulsion pH	90	4.45 < 5.83 < 6.30
Model system	Water separation	90	2.30 < 2.56 < 3.84
Model system	Fat separation	90	.32 < .36 < .40
Model system	Moisture	90	56.8 < 63.1 < 70.0
Model system	Fat	90	17.9 < 19.9 < 22.1
Model system	Protein	90	11.5 < 12.8 < 14.2
Model system	Ash	90	3.8 < 4.2 < 4.7
Model system	CIE L*	90	72.1 < 80.1 < 88.9
Model system	CIE a*	90	11.1 < 12.3 < 13.7
Model system	CIE b*	90	15.0 < 16.7 < 18.5
Model system	Peak force	85	128 < 150 < 177
Model system	Internal force	85	108 < 127 < 150
Model system	TA.XT2i cohesiveness	85	.50 < .59 < .70
Model system	TA.XT2i chewiness	85	23613 < 27780 < 32780
Model system	TA.XT2i springiness	85	11.7 < 13.8 < 16.3
Model system	TA.XT2i hardness	85	8228 < 9680 < 11422

[a] Equivalence percent = percent used to determine the lower and upper level of equivalence from the control. Percent limit set to determine that treatment samples are x percent equivalent to the control sample.

[b] Equivalence range = lower level of equivalence < control < upper level of equivalence.

Table 4.6. Equivalence range determination for processing, proximate analysis, color, purge, puncture, texture and sensory characteristics as measured on the least squares means from control and experimental frankfurters formulated with a portion of lean replaced by various protein ingredients.

Production system	Measured variable	Equivalence (%) [a]	Equivalence range [b]
Frankfurter system	Smokehouse yield	90	81.7 < 90.8 < 100
Frankfurter system	Water separation	90	2.75 < 3.05 < 3.39
Frankfurter system	Fat separation	90	.54 < .60 < .67
Frankfurter system	Moisture	90	51.3 < 57.0 < 63.3
Frankfurter system	Fat	90	22.8 < 25.3 < 28.1
Frankfurter system	Protein	90	11.4 < 12.7 < 14.1
Frankfurter system	Ash	90	4.5 < 5.0 < 5.6
Frankfurter system	CIE L*	90	66.4 < 73.8 < 81.9
Frankfurter system	CIE a*	90	14.2 < 15.8 < 17.5
Frankfurter system	CIE b*	90	14.2 < 15.8 < 17.5
Frankfurter system	Purge	90	.78 < .87 < .97
Frankfurter system	Peak force	85	455 < 535 < 631
Frankfurter system	Internal force	85	121 < 142 < 168
Frankfurter system	TA.XT2i cohesiveness	85	.57 < .67 < .79
Frankfurter system	TA.XT2i chewiness	85	36890 < 43400 < 51212
Frankfurter system	TA.XT2i springiness	85	14.5 < 17.0 < 20.1
Frankfurter system	TA.XT2i hardness	85	5602 < 6590 < 7776
Frankfurter system	Sensory cohesiveness	85	6.6 <7.8 < 9.2
Frankfurter system	Sensory chewiness	85	7.1 < 8.4 < 9.9
Frankfurter system	Sensory springiness	85	9.1 < 10.7 < 12.6
Frankfurter system	Sensory hardness	85	7.9 < 9.3 < 11.0
Frankfurter system	Sensory toughness	85	9.9 < 11.6 < 13.7

[a] Equivalence percent = percent used to determine the lower and upper level of equivalence from the control. Percent limit set to determine that treatment frankfurters are x percent equivalent to the control frankfurter.

[b] Equivalence range = lower level of equivalence < control < upper level of equivalence.

Table 4.7. Least squares means and equivalence for pork emulsion cook yields (%) from control and experimental samples formulated with a portion of lean replaced by various protein ingredients, as measured with a modified Townsend (1968) method.

Treatment	Yield (%) [a]
Control [b]	99.1 [e]
Gelling Plasma – 1% [c]	98.7 [e]
Myogel – 1% [c]	99.1 [e]
Myogel Plus – 1% [c]	99.3 [e]
Chicken Collagen – 1% [c]	99.1 [e]
Turkey Collagen – 1% [c]	99.0 [e]
SEM [d]	0.12

[a] Yield = Percent yield = (cooked weight / raw weight) x 100.
[b] Control = No lean meat replacement.
[c] 1% Treatment = 4% of the lean meat component in the emulsion formulation was replaced by 1% treatment ingredient and 3% water.
[d] SEM = Standard error of the means for the yield values of the control and experimental samples.
[e] Means within the same column with the same superscripts are equivalent to the control ($P<0.05$). A 90 percent equivalence range for percent yield = 89.2 < 99.1 < 100.

Table 4.8. Least squares means and equivalence for frankfurter smokehouse yields (%) from control and experimental frankfurters formulated with a portion of lean replaced by protein ingredients.

Treatment	Smokehouse Yield (%) [a]
Control [b]	90.8 [e]
Gelling Plasma – 1% [c]	91.1 [e]
Myogel – 1% [c]	90.7 [e]
Myogel Plus – 1% [c]	91.2 [e]
Chicken Collagen – 1% [c]	91.2 [e]
Turkey Collagen – 1% [c]	91.2 [e]
SEM [d]	0.38

[a] Smokehouse yield = Percent cold yield = (cold cooked weight / raw weight) x 100.
[b] Control = No lean meat replacement.
[c] 1% Treatment = 4% of the lean meat component in the emulsion formulation was replaced by 1% treatment ingredient and 3% water.
[d] SEM = Standard error of the means for the smokehouse yield values of the control and experimental frankfurters.
[e] Means within the same column with the same superscripts are equivalent to the control ($P<0.05$). A 90 percent equivalence range for percent smokehouse yield = $81.7 < 90.8 < 100$.

Table 4.9. Least squares means and equivalence for pH of raw emulsion and cooked control and experimental samples formulated with a portion of lean replaced by various protein ingredients and produced by a modified Townsend (1968) method, as measured with a pH-STAR Pistol (SFK Technology).

Treatment	Raw Emulsion pH [a]	Cooked Sample pH [b]
Control [c]	5.58 [f]	5.83 [f]
Gelling Plasma – 1% [d]	5.63 [f]	5.86 [f]
Myogel – 1% [d]	5.65 [f]	5.86 [f]
Myogel Plus – 1% [d]	5.65 [f]	5.86 [f]
Chicken Collagen – 1% [d]	5.63 [f]	5.87 [f]
Turkey Collagen – 1% [d]	5.64 [f]	5.87 [f]
SEM [e]	0.015	0.009

[a] Raw emulsion pH = pH taken of the raw emulsions with all ingredients at the end of emulsion production.

[b] Cooked sample pH = pH taken of the cooked samples with all ingredients after hot water bath cooking.

[c] Control = No lean meat replacement.

[d] 1% Treatment = 4% of the lean meat component in the emulsion formulation was replaced by 1% treatment ingredient and 3% water.

[e] SEM = Standard error of the means for the raw emulsion pH and cooked sample pH values of the control and experimental samples.

[f] Means within the same column with the same superscripts are equivalent to the control ($P<0.05$). A 90 percent equivalence range for raw emulsion pH = $4.27 < 5.58 < 5.99$. A 90 percent equivalence range for cooked sample pH = $4.45 < 5.83 < 6.30$. Equivalence ranges on pH were determined by using the inverse log of the control pH.

Table 4.10. Least squares means and equivalence for water separation (%) and fat separation (%) from control and experimental samples formulated with a portion of lean replaced by various protein ingredients and produced by a modified Townsend (1968) method, as measured with a Rongey (1965) method.

Treatment	Water Separation (%) [a]	Fat Separation (%) [b]
Control [c]	2.56 [f]	0.36 [f]
Gelling Plasma – 1% [d]	2.27 [g]	0.37 [g]
Myogel – 1% [d]	2.68 [g]	0.47 [g]
Myogel Plus – 1% [d]	2.36 [g]	0.35 [g]
Chicken Collagen – 1% [d]	2.77 [g]	0.42 [g]
Turkey Collagen – 1% [d]	2.16 [g]	0.27 [g]
SEM [e]	0.37	0.04

[a] Water separation = Percent water separation = (ml of water / sample weight) x 100.
[b] Fat separation = Percent fat separation = (ml of fat / sample weight) x 100.
[c] Control = No lean meat replacement.
[d] 1% Treatment = 4% of the lean meat component in the emulsion formulation was replaced by 1% treatment ingredient and 3% water.
[e] SEM = Standard error of the means for the water and fat separation values of the control and experimental samples.
[fg] Means within the same column with the same superscripts are equivalent to the control ($P<0.05$). A 90 percent equivalence range for percent water separation = $2.30 < 2.56 < 2.84$. A 90 percent equivalence range for percent fat separation = $.32 < .36 < .4$.

Table 4.11. Least squares means and equivalence for water separation (%) and fat separation (%) from control samples and experimental samples formulated with a portion of lean replaced by various protein ingredients, as measured with a Rongey (1965) method.

Treatment	Water Separation (%) [a]	Fat Separation (%) [b]
Control [c]	3.05 [f]	0.60 [f]
Gelling Plasma – 1% [d]	3.38 [g]	0.58 [g]
Myogel – 1% [d]	3.31 [g]	0.57 [g]
Myogel Plus – 1% [d]	3.07 [g]	0.54 [g]
Chicken Collagen – 1% [d]	3.19 [g]	0.48 [g]
Turkey Collagen – 1% [d]	3.97 [g]	0.70 [g]
SEM [e]	0.36	0.08

[a] Water separation = Percent water separation = (ml of water / sample weight) x 100.
[b] Fat separation = Percent fat separation = (ml of fat / sample weight) x 100.
[c] Control = No lean meat replacement.
[d] 1% Treatment = 4% of the lean meat component in the emulsion formulation was replaced by 1% treatment ingredient and 3% water.
[e] SEM = Standard error of the means for the water and aft separation values of the control and experimental samples.
[fg] Means within the same column with the same superscripts are equivalent to the control ($P<0.05$). A 90 percent equivalence range for percent water separation = $2.75 < 3.05 < 3.39$. A 90 percent equivalence range for percent fat separation = $.54 < .60 < .67$.

Table 4.12. Least squares means and equivalence for moisture (%), fat (%), protein (%), and ash (%) from control and experimental samples formulated with a portion of lean replaced by various protein ingredients and produced by a modified Townsend (1968) method, as measured by AOAC methods [a].

Treatment	Moisture (%)	Fat (%)	Protein (%)	Ash (%)
Control [b]	63.1 [e]	19.9 [e]	12.8 [e]	4.2 [e]
Gelling Plasma – 1% [c]	63.0 [e]	20.1 [e]	12.6 [e]	4.3 [e]
Myogel – 1% [c]	63.1 [e]	20.1 [e]	12.5 [e]	4.3 [e]
Myogel Plus – 1% [c]	63.2 [e]	20.1 [e]	12.6 [e]	4.2 [e]
Chicken Collagen – 1% [c]	63.1 [e]	20.1 [e]	12.5 [e]	4.4 [e]
Turkey Collagen – 1% [c]	62.9 [e]	20.1 [e]	12.6 [e]	4.3 [e]
SEM [d]	0.14	0.16	0.06	0.07

[a] AOAC methods = Moisture was measured using the AOAC (1990b) method – Moisture in meat.
Fat was measured using the AOAC (1990a) method – Fat (crude) or ether extract in meat.
Protein was measured using the AOAC (1993) method – Crude protein in meat and meat products.
Ash was determined by adding the fat, moisture, and protein values together and subtracting the total from 100.

[b] Control = No lean meat replacement.

[c] 1% Treatment = 4% of the lean meat component in the emulsion formulation was replaced by 1% treatment ingredient and 3% water.

[d] SEM = Standard error of the means for the moisture, fat, protein, and ash values of the control and experimental samples.

[e] Means within the same column with the same superscripts are equivalent to the control ($P<0.05$). A 90 percent equivalence range for percent moisture = $56.8 < 63.1 < 70.0$. A 90 percent equivalence range for percent fat = $17.9 < 19.9 < 22.1$. A 90 percent equivalence range for percent protein = $11.5 < 12.8 < 14.2$. A 90 percent equivalence range for percent ash = $3.8 < 4.2 < 4.7$.

Table 4.13. Least squares means and equivalence for moisture (%), fat (%), protein (%), and ash (%) from control and experimental frankfurters formulated with a portion of lean replaced by various protein ingredients, as measured by AOAC methods [a].

Treatment	Moisture (%)	Fat (%)	Protein (%)	Ash (%)
Control [b]	57.0 [e]	25.3 [e]	12.7 [e]	5.0 [e]
Gelling Plasma – 1% [c]	57.4 [e]	24.8 [f]	12.6 [e]	5.3 [f]
Myogel – 1% [c]	57.5 [e]	25.2 [e]	12.3 [e]	5.0 [f]
Myogel Plus – 1% [c]	58.7 [e]	23.8 [f]	12.6 [e]	4.9 [f]
Chicken Collagen – 1% [c]	57.7 [e]	24.7 [f]	12.7 [e]	5.0 [f]
Turkey Collagen – 1% [c]	57.9 [e]	24.6 [f]	12.7 [e]	4.8 [f]
SEM [d]	0.57	0.89	0.29	0.24

[a] AOAC methods = Moisture was measured using the AOAC (1990b) method – Moisture in meat.
Fat was measured using the AOAC (1990a) method – Fat (crude) or ether extract in meat.
Protein was measured using the AOAC (1993) method – Crude protein in meat and meat products.
Ash was determined by adding the fat, moisture, and protein values together and subtracting the total from 100.

[b] Control = No lean meat replacement.

[c] 1% Treatment = 4% of the lean meat component in the emulsion formulation was replaced by 1% treatment ingredient and 3% water.

[d] SEM = Standard error of the means for the moisture, fat, protein, and ash values of the control and experimental frankfurters.

[ef] Means within the same column with the same superscripts are equivalent to the control ($P<0.05$). A 90 percent equivalence range for percent moisture = 51.3 < 57.0 < 63.3. A 90 percent equivalence range for percent fat = 22.8 < 25.3 < 28.1. A 90 percent equivalence range for percent protein = 11.4 < 12.7 < 14.1. A 90 percent equivalence range for percent ash = 4.5 < 5.0 < 5.6.

Table 4.14. Least squares means and equivalence for CIE L* (lightness), a* (redness/greenness), and b* (yellowness/blueness) from control and experimental samples formulated with a portion of lean replaced by various protein ingredients and produced by a modified Townsend (1968) method, as measured by a Hunterlab Labscan instrument (Model LS, 1500).

Treatment	L* (lightness)	a* (redness/greenness)	b* (yellowness/blueness)
Control [a]	80.1 [d]	12.3 [d]	16.7 [d]
Gelling Plasma – 1% [b]	79.8 [d]	12.4 [d]	16.6 [d]
Myogel – 1% [b]	79.4 [d]	12.3 [d]	16.4 [d]
Myogel Plus – 1% [b]	79.2 [d]	12.5 [d]	16.8 [d]
Chicken Collagen – 1% [b]	79.5 [d]	12.4 [d]	16.7 [d]
Turkey Collagen – 1% [b]	79.6 [d]	12.4 [d]	16.6 [d]
SEM [c]	0.16	0.13	0.15

[a] Control = No lean meat replacement.
[b] 1% Treatment = 4% of the lean meat component in the emulsion formulation was replaced by 1% treatment ingredient and 3% water.
[c] SEM = Standard error of the means for the CIE L8, a*, and b* values of the control and experimental samples.
[d] Means within the same column with the same superscripts are equivalent to the control ($P<0.05$). A 90 percent equivalence range for CIE L* = 72.1 < 80.1 < 88.9. A 90 percent equivalence range for CIE a* = 11.1 < 12.3 < 13.7. A 90 percent equivalence range for CIE b* = 15.0 < 16.7 < 18.5.

Table 4.15. Least squares means and equivalence for CIE L* (lightness), a* (redness/greenness), and b* (yellowness/blueness) from control and experimental frankfurters formulated with a portion of lean replaced by various protein ingredients, as measured by a Hunterlab Labscan instrument (Model LS, 1500).

Treatment	L* (lightness)	a* (redness/greenness)	b* (yellowness/blueness)
Control [a]	73.8 [d]	15.8 [d]	15.8 [d]
Gelling Plasma – 1% [b]	74.5 [d]	15.4 [d]	16.1 [d]
Myogel – 1% [b]	74.0 [d]	15.3 [d]	16.1 [d]
Myogel Plus – 1% [b]	73.7 [d]	14.2 [e]	16.6 [d]
Chicken Collagen – 1% [b]	73.4 [d]	15.8 [d]	16.2 [d]
Turkey Collagen – 1% [b]	73.5 [d]	15.1 [d]	16.7 [e]
SEM [c]	0.49	0.34	0.30

[a] Control = No lean meat replacement.
[b] 1% Treatment = 4% of the lean meat component in the emulsion formulation was replaced by 1% treatment ingredient and 3% water.
[c] SEM = Standard error of the means for the CIE L*, a*, and b* values of the control and experimental frankfurters.
[de] Means within the same column with the same superscripts are equivalent to the control ($P<0.05$). A 90 percent equivalence range for CIE L* = 66.4 < 73.8 < 81.9. A 90 percent equivalence range for CIE a* = 14.2 < 15.8 < 17.5. A 90 percent equivalence range for CIE b* = 14.2 < 15.8 < 17.5.

Table 4.16. Least squares means and equivalence for pork emulsion purge (%) from control and experimental frankfurters formulated with a portion of lean replaced by protein ingredients as measured on day 1 (one day after packaging), day 7, day 14, day 21, and day 28 for each replication

Treatment	Purge (%) [a]
Control [b]	0.87 [e]
Gelling Plasma – 1% [c]	0.94 [f]
Myogel – 1% [c]	0.74 [f]
Myogel Plus – 1% [c]	0.85 [f]
Chicken Collagen – 1% [c]	0.96 [f]
Turkey Collagen – 1% [c]	1.05 [f]
SEM [d]	0.06

[a] Percent purge = ((frankfurter weight + dried package weight) / initial package weight) x 100
[b] Control = No lean meat replacement.
[c] 1% Treatment = 4% of the lean meat component in the emulsion formulation was replaced by 1% treatment ingredient and 3% water.
[d] SEM = Standard error of the means for the purge values of the control and experimental frankfurters.
[ef] Means within the same column with the same superscripts are equivalent to the control ($P<0.05$). A 90 percent equivalence range for percent purge = .78 < .87 < .97.

Table 4.17. Least squares means for and equivalence peak force (gm of force) and internal force (gm of force) control and experimental samples formulated with a portion of lean replaced by various protein ingredients and produced by a modified Townsend (1968) method, as measured with a TA.XT2i Texture Analyzer (Texture Technologies Corp.).

Treatment	Peak Force (gm of force) [a]	Internal Force (gm of force) [b]
Control [c]	150 [f]	127 [f]
Gelling Plasma – 1% [d]	138 [f]	117 [f]
Myogel – 1% [d]	138 [f]	116 [f]
Myogel Plus – 1% [d]	132 [g]	116 [f]
Chicken Collagen – 1% [d]	133 [f]	115 [f]
Turkey Collagen – 1% [d]	141 [f]	115 [f]
SEM [e]	3.5	2.2

[a] Peak force = Force required to break the outer surface or skin of the frankfurter (exterior firmness).

[b] Internal force = Force required to penetrate break the interior of the frankfurter (average interior firmness).

[c] Control = No lean meat replacement.

[d] 1% Treatment = 4% of the lean meat component in the emulsion formulation was replaced by 1% treatment ingredient and 3% water.

[e] SEM = Standard error of the means for the peak force and internal force values of the control and experimental samples.

[f] Means within the same column with the same superscripts are equivalent to the control ($P<0.05$). An 85 percent equivalence range for peak force = $128 < 150 < 177$. An 85 percent equivalence range for internal force= $108 < 127 < 150$.

Table 4.18. Least squares means and equivalence for peak force (gm of force) and internal force (gm of force) control and experimental frankfurters formulated with a portion of lean replaced by various protein ingredients, as measured with a TA.XT2i Texture Analyzer (Texture Technologies Corp.).

Treatment	Peak Force (gm of force) [a]	Internal Force (gm of force) [b]
Control [c]	535 [f]	142 [f]
Gelling Plasma – 1% [d]	508 [g]	142 [f]
Myogel – 1% [d]	455 [g]	137 [f]
Myogel Plus – 1% [d]	495 [g]	146 [f]
Chicken Collagen – 1% [d]	490 [g]	137 [f]
Turkey Collagen – 1% [d]	480 [g]	138 [f]
SEM [e]	36	5.0

[a] Peak force = Force required to break the outer surface or skin of the frankfurter (exterior firmness).

[b] Internal force = Force required to penetrate break the interior of the frankfurter (average interior firmness).

[c] Control = No lean meat replacement.

[d] 1% Treatment = 4% of the lean meat component in the emulsion formulation was replaced by 1% treatment ingredient and 3% water.

[e] SEM = Standard error of the means for the peak force and internal force values of the control and experimental frankfurters.

[fg] Means within the same column with the same superscripts are equivalent to the control ($P<0.05$). An 85 percent equivalence range for peak force = $455 < 535 < 631$. An 85 percent equivalence range for internal force= $121 < 142 < 168$.

Table 4.19. Least squares means and equivalence for cohesiveness, chewiness (gm of force), springiness (mm of distance), and hardness (gm of force) from control and experimental samples formulated with a portion of lean replaced by various protein ingredients and produced by a modified Townsend (1968) method, as measured by a TA.XT2i Texture Analyzer (Texture Technologies Corp.).

Treatment	Cohesiveness [a]	Chewiness (gm of force) [b]	Springiness (mm of distance) [c]	Hardness (gm of force) [d]
Control [e]	0.59 [h]	27780 [h]	13.8 [h]	9680 [h]
Gelling Plasma – 1% [f]	0.61 [h]	26520 [h]	13.6 [h]	9710 [h]
Myogel – 1% [f]	0.60 [h]	25840 [h]	13.8 [h]	7790 [i]
Myogel Plus – 1% [f]	0.60 [h]	24570 [h]	14.0 [h]	8510 [i]
Chicken Collagen – 1% [f]	0.59 [h]	23910 [i]	13.7 [h]	7480 [i]
Turkey Collagen – 1% [f]	0.59 [h]	25360 [h]	13.6 [h]	7950 [i]
SEM [g]	0.006	640	0.30	350

[a] Cohesiveness = The ratio of the positive force area during the second compression to that during the first compression (Area 2/Area 1).
[b] Chewiness = The product of gumminess times cohesiveness times springiness.
[c] Springiness = The distance or length of compression cycle during the second compression.
[d] Hardness = The force at maximum compression during first compression.
[e] Control = No lean meat replacement.
[f] 1% Treatment = 4% of the lean meat component in the emulsion formulation was replaced by 1% treatment ingredient and 3% water.
[g] SEM = Standard error of the means for the cohesiveness, chewiness, springiness, and hardness values of the control and experimental samples.
[hi] Means within the same column with the same superscripts are equivalent to the control ($P<0.05$). An 85 percent equivalence range for cohesiveness = .50 < .59 < .70. An 85 percent equivalence range for chewiness = 23613 < 27780 < 32780. An 85 percent equivalence range for springiness = 11.7 < 13.8 < 16.3. An 85 percent equivalence range for hardness = 8228 < 9680 < 11422.

Table 4.20. Least squares means and equivalence for cohesiveness, chewiness (gm of force), springiness (mm of distance), and hardness (gm of force) from control and experimental frankfurters formulated with a portion of lean replaced by various protein ingredients, as measured by a TA.XT2i Texture Analyzer (Texture Technologies Corp.).

Treatment	Cohesiveness [a]	Chewiness (gm of force) [b]	Springiness (mm of distance) [c]	Hardness (gm of force) [d]
Control [e]	0.67 [h]	43400 [h]	17.0 [h]	6590 [h]
Gelling Plasma – 1% [f]	0.65 [h]	38440 [i]	17.3 [h]	5880 [i]
Myogel – 1% [f]	0.64 [h]	35400 [i]	17.4 [h]	6320 [i]
Myogel Plus – 1% [f]	0.66 [h]	38500 [i]	16.8 [h]	6550 [i]
Chicken Collagen – 1% [f]	0.64 [h]	35600 [i]	17.2 [h]	6420 [i]
Turkey Collagen – 1% [f]	0.66 [h]	34400 [i]	16.9 [h]	6430 [i]
SEM [g]	0.015	2750	0.21	540

[a] Cohesiveness = The ratio of the positive force area during the second compression to that during the first compression (Area 2/Area 1).
[b] Chewiness = The product of gumminess times cohesiveness times springiness.
[c] Springiness = The distance or length of compression cycle during the second compression.
[d] Hardness = The force at maximum compression during first compression.
[e] Control = No lean meat replacement.
[f] 1% Treatment = 4% of the lean meat component in the emulsion formulation was replaced by 1% treatment ingredient and 3% water.
[g] SEM = Standard error of the means for the cohesiveness, chewiness, springiness, and hardness values of the control and experimental frankfurters.
[hi] Means within the same column with the same superscripts are equivalent to the control ($P<0.05$). An 85 percent equivalence range for cohesiveness = .57 < .67 < .79. An 85 percent equivalence range for chewiness = 36890 < 43400 < 51212. An 85 percent equivalence range for springiness = 14.5 < 17.0 < 20.1. An 85 percent equivalence range for hardness = 5602 < 6590 < 7776.

Table 4.21. Least squares means and equivalence for cohesiveness, chewiness, springiness, hardness, and skin toughness from control and experimental frankfurters formulated with a portion of lean replaced by various protein ingredients, as measured by a trained sensory panel using a line scale (numerical value of 15 units) for each of the parameters with descriptive anchors.

Treatment	Cohesiveness [a]	Chewiness [b]	Springiness [c]	Hardness [d]	Skin Toughness [e]
Control [f]	7.8 [i]	8.4 [i]	10.7 [i]	9.3 [i]	11.6 [i]
Gelling Plasma – 1% [g]	7.7 [i]	7.0 [j]	9.8 [j]	8.1 [j]	11.0 [i]
Myogel – 1% [g]	7.6 [i]	7.0 [j]	9.5 [j]	7.6 [j]	10.5 [j]
Myogel Plus – 1% [g]	7.5 [i]	8.2 [i]	9.9 [i]	8.5 [i]	10.9 [i]
Chicken Collagen – 1% [g]	7.4 [i]	7.4 [j]	9.2 [j]	7.4 [j]	10.3 [j]
Turkey Collagen – 1% [g]	7.6 [i]	7.2 [j]	8.8 [j]	7.2 [j]	10.3 [j]
SEM [h]	0.43	0.31	0.47	0.50	0.42

[a] Cohesiveness = The degree to which the frankfurter deforms before it ruptures.
[b] Chewiness = The amount of chewing required to prepare the frankfurter for swallowing.
[c] Springiness = The degree to which the frankfurter returns to its original shape.
[d] Hardness = The force to bite completely through the frankfurter.
[e] Toughness = The force to required to penetrate through the surface of the frankfurter.
[f] Control = No lean meat replacement.
[g] 1% Treatment = 4% of the lean meat component in the emulsion formulation was replaced by 1% treatment ingredient and 3% water.
[h] SEM = Standard error of the means for the cohesiveness, chewiness, springiness, hardness, and toughness values of the control and experimental frankfurters.
[ij] Means within the same column with the same superscripts are equivalent to the control ($P<0.05$). An 85 percent equivalence range for cohesiveness = $6.6 < 7.8 < 9.2$. An 85 percent equivalence range for chewiness = $7.1 < 8.4 < 9.9$. A 85 percent equivalence range for springiness = $9.1 < 10.7 < 12.6$. An 85 percent equivalence range for hardness = $7.9 < 9.3 < 11.0$. An 85 percent equivalence range for toughness = $9.9 < 11.6 < 13.7$.

Figure 4.1. Sensory evaluation score sheet used to measure texture characteristics of control and experimental frankfurters formulated with a portion of lean replaced by various protein ingredients, as measured by using a line scale (numerical value of 15 units) with descriptive anchors for each of the texture parameters.

Date _____
ID _____
Sample Code _____

Please make a horizontal mark on each line to indicate your perception of the textural attributes of the sample.

Toughness: Place the sample between the incisors so that you will be able to bite through the skin. Bite down evenly, and evaluate the force to penetrate through the surface

Very soft — Very tough

Hardness: Place the sample between your molars as described above, bite down evenly, and evaluate the force to bite completely through the sample.

Very soft — Very hard

Cohessiveness: Place the sample between your molars as described above, compress it fully and evaluate the degree to which the sample deforms before it ruptures. A sample with high cohesiveness will undergo much deformation before it ruptures. A sample with low cohesiveness ruptures with little deformation.

Not cohesive — Very cohesive

Springiness: Place the sample between your molars, with the cut edges adjacent to the surface of the molars. Compress partially without breaking, release, and evaluate the degree to which the sample returns to its original shape.

Not springy — Very springy

Chewiness: Place sample between molars and evaluate the amount of chewing required to prepare the sample for swallowing.

Not chewy — Very chewy

Juciness: The progressive increase in the sensation of moisture in the mouth during chewing

Not juicy — Very juicy

CHAPTER 5. THE EFFECT OF LEAN MEAT REPLACEMENT BY POULTRY COLLAGENS ON THE PROPERTIES OF FRANKFURTERS

A paper to be submitted to The *Journal of Food Science*

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Abstract

The effects of replacing a portion of the lean meat block with chicken or turkey collagen in frankfurter formulations were measured. The characteristics measured included smokehouse yield, proximate composition (moisture, fat, protein, ash), color (CIE L*, a*, b*), purge, texture, sensory attributes, and consumer acceptance. Both types of poultry collagens used and replacement levels created minimal differences in proximate composition and no significant ($P>0.05$) effect on L* values, a* values, and purge when compared to the control. Although significant ($P<0.05$) differences were found for sensory characteristics, those differences were not unacceptable to a consumer panel. These results would indicate that the use of poultry collagens to replace a portion of the lean in frankfurter formulations should be considered to economically produce a consumer-acceptable product.

Keywords: Poultry Protein Ingredients, Meat Replacement

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Introduction

In 2000, 4.9 million pounds of frankfurters were sold to foodservice establishments, due to new rotating menu items and the introduction of the "Big Griller" by McDonald's restaurants. The frankfurter retail sales market also increased the next year in 2001, when 808 million pounds of retail frankfurters were sold (Salvage 2002). These sales figures emphasize the demand for this type of product. In order to maintain or improve these sales figures while increasing profits for the processor, processors must make sure that palatability and value are not compromised. Mandigo (1991) stated that consumers purchase meat products because they like the product. Return purchasing decisions of a particular product will be made due its sensory acceptability, regardless of how the product was produced.

Due to basic business economics, many aspects of production need to be evaluated to determine the most cost effective production methods. One of the main expenses in the production of frankfurters is from the cost of the raw materials utilized in the processed meat formulations. There are many nonmeat proteins (i.e. soy protein, milk protein, etc.) available to either take the place of meat proteins or to extend the final yields of the processed meat products. On the other hand, meat-derived proteins (e.g. collagen) are also being considered in meat formulations to replace a portion of the lean meat.

Collagen is present in comminuted meats and meat products either as a natural component of the connective tissue of the meat or more recently applied as an additive or ingredient. Collagen is often considered a nonfunctional meat component for binding properties. Collagen can be effective for binding fat in emulsion meat products (i.e. frankfurters, bologna, etc.) and has also been proven to be effective as a water binder in these emulsion products.

Saffle and others (1964) reported undesirable characteristics such as poor peelability, unstable batters (meat emulsions), gel pocket formation, and wrinkling of the outer skin that have been associated with sausage products containing large quantities of high collagen meats. Increased research and understanding of collagens have reversed the undesirable opinions surrounding the use of collagen in processed meat formulations.

Bailey and Light (1989) listed hide/skin collagen, bone collagen, offal collagen, and skeletal muscle collagen as sources of collagen to be used in sausage manufacturing. The majority of research conducted using connective tissue/collagen has been performed in finely comminuted meat systems. The sources of connective tissue/collagen used in research are quite numerous: beef tripe (Randall an others 1976; Jones and others 1982); tendon from beef hind leg muscles (Sadler and Young 1993); desinewed cow meat (Ladwig and others 1989); desinewed shank muscles from beef carcasses (Eilert and Mandigo 1993; Eilert and others 1996ab; Calhoun and others 1996ab; Osburn and others 1999); desinewed connective tissues from pork (Delmore and Mandigo 1994); beef skin (Satterlee and others 1973; Asghar and Henrickson 1982; Rao and Henrickson 1983, Chavez and others 1985); pork skin (Satterlee and others 1973; Sadowska and others 1980; Puolanne and Ruusunen 1981; Quint and others 1987; Delmore and Mandigo 1994; Fojtik 1997; Osburn and others 1997; Prabhu and Doerscher 2000); chicken skin (Osburn and Mandigo 1998; Prabhu 2003); turkey skin (Acton and Dick 1978; Prabhu 2003); and meats containing high amounts of connective tissue (Maurer and Baker 1966; Carpenter and others 1979; Ambrosiadis and Wirth 1984).

Although poultry skin (e.g chicken and turkey) is a source of collagen that may be used in comminuted meat systems, it has not been generally accepted by processed meat producers. According to Marsden (1981), the natural skin content of whole turkey carcasses

is 15 percent while whole chicken carcass is approximately 20 percent. Campbell and Kenney (1994) listed poultry skin as generally being a filler ingredient in poultry or mixed specie batter sausages. The authors described that poultry skin may be listed on ingredient labels as "poultry by-products" and in other products skin cannot be added in higher proportion than occurs naturally.

Due to its high collagen content, broiler skin meat possessed inferior emulsifying capacity (Maurer and Baker 1966). Moreover, Hudspeth and May (1969) analyzed skin, heart, and gizzard tissues of turkeys, hens, broilers, and ducklings for emulsifying capacity of salt-soluble protein. The authors reported that skin was the least desirable tissue in emulsification properties and was not as effective in emulsifying ability as muscle tissue from the same class of poultry. Smolińska and others (1988) found a replacement of 5 percent leg muscles with chicken skin did not change sausage binding and over sensory value, but reduced water-holding capacity and palatability of sausages.

On the other hand, other research has contradicted the adverse affects created by the use of poultry skin. Baker and others (1968) studied the effect of level of chicken skin on the eating quality of chicken frankfurters. Skin levels in the range of 5 to 20 percent had little effect on the tenderness or juiciness of the finished product. The authors concluded that the addition of chicken skin did not make the finished frankfurters mushy; that, on the contrary, at the levels above 20 percent, the frankfurters were evaluated as more firm and chewy. Schnell and others (1973) also studied the effect of percent chicken skin on the eating quality of chicken frankfurters. The authors reported that the presence of chicken skin in the formulation increased tenderness and viscosity. It was again concluded that chicken skin did not adversely affect the overall acceptability of the finished product.

However, there was a significant ($P<0.05$) decrease in product acceptability when 30 percent chicken skin was added to the frankfurters.

Acton and Dick (1978) produced poultry loaves with turkey thigh meat and proportions of turkey skin ranging from 10 to 50 percent of the formulation. The authors reported significant ($P<0.05$) increases in cooking loss as the skin content of the loaves increased, which was due primarily to the shift in moisture and fat ratios of the formulations. Similar shear forces for all treatments were reported and redness values decreased as the turkey skin levels increased.

Bonifer and others (1996) evaluated the functional properties of washed chicken skin in a bologna product at the levels of 0, 10, and 20 percent. Chicken skin content did not affect fat or gel-water losses and lowered solids loss when compared to bologna with no chicken skin ($P<0.05$). Kramer Shear peak force was not significantly different ($P<0.05$) for bologna at each treatment level. The authors also reported that the addition of chicken skin did not affect compression measurements of hardness, springiness, cohesiveness, and chewiniess when compared to bologna with 0 percent skin. The addition of the chicken skin resulted in a lighter, less red, and less yellow product according to HunterLab color analysis ($P<0.05$). Consumer panelists rated bologna with 10% chicken skin highest in texture, flavor and appearance acceptability ($P<0.05$).

Osburn and Mandigo (1998) researched reduced-fat bologna manufactured with poultry skin connective tissue. The authors manufactured added water (100, 200, and 300 percent) chicken skin connective tissue gels and then incorporated varying levels (10 to 30 percent) of the gels into reduced-fat bologna formulations. All bologna treatments exhibited acceptable sensory attributes. The authors concluded that it was feasible to use lower

added water chicken skin connective tissue gels as a texture modifying agent in reduced-fat comminuted meat products.

More recently, Prabhu (2003) reported that functional collagen proteins from chicken and turkey skins can bind three to four times their weight in water and can form a firm elastic "cold" gel producing texture characteristics that are similar to meat. Prabhu stated that this gel functions as a matrix stabilizer of finely comminuted and coarse-ground meat products such as frankfurters or sausages. The author suggested that collagens immobilize free water and prevent moisture loss during heat processing as well as improve texture while reducing purge loss.

Prabhu (2003) reported that these new poultry collagens have been researched in numerous processed meat products such as chicken nuggets, breakfast sausage, coarse-ground smoked sausages, and fresh ground meat products (i.e. turkey burger). Prabhu (2003) controlled purge and texture of turkey smoked sausages when 5 percent of the turkey thigh meat was replaced with 1 percent turkey collagen and 4 percent water. Furthermore, a cost savings of 3.1 percent was recognized. It was also reported that poultry collagens could be incorporated by either tumbling or massaging the collagen into whole muscle meat products such as chicken breast and chicken wings. The overall result of adding 1 percent to 2 percent poultry collagen to replace a portion of the lean meat block are numerous. A substantial cost savings could be achieved without the reduction in nutritional or eating quality characteristics of the final processed meat product.

To comply with the United States Department of Agriculture's (USDA) regulations, frankfurter producers must follow the guidelines outlined in the Code of Federal Regulations (CFR) (USDA 2002). Poultry collagens were recently approved as a flavoring in standard and non-standard processed meat and poultry products by the USDA's Food Safety and

Inspection Service (FSIS) in March of 2001. The collagens were approved to be used at a level sufficient for purpose. This USDA/FSIS ruling allows flexibility and opportunity in the manufacture of cooked sausages such as frankfurters.

Because of the availability of proteins (collagen) from poultry origin, there is a great increase in their use as a substitute for more expensive proteins from animal origin. The objective of this study was to research the effectiveness of utilizing poultry collagens as a meat replacement in frankfurter formulations. Although meat processors consistently strive for reducing the costs of production, product quality characteristics can't be compromised.

Materials and Methods

Preparing the Meat Block

The lean pork source (picnic cushion meat - 88/12) was purchased from Iowa Packing Company (Des Moines, IA). After receiving the pork trim, it was subsequently frozen in the blast freezer (-34 °C) and moved the next day into another freezer (-28 °C). Prior to processing, the lean pork was tempered to 1 °C in a cooler at 2 °C for initial grinding. Grinding took place one day prior to emulsion production. The lean was crust frozen in the blast freezer to aid in the grinding process and maintain the temperature at -1 °C.

The lean pork was ground (Biro grinder, Model 7552, Marblehead, OH) through a 1.27 cm grinder plate. A 5.90 kg sample was randomly taken to determine the fat content using an Anyl Ray Fat Analyzer (Kartrig Pak, Model 316-48, Davenport, IA). The lean was then batched into individual treatments according to the required weight in meat lugs. The meat was then placed into the cooler (0 °C) until further processing the next day.

Preparing the Pork Trim 50/50

The fat pork source (pork trim - 50/50) was also purchased from Iowa Packing Company (Des Moines, IA). After receiving the pork trim, it was subsequently frozen in the blast freezer (-34 °C) and moved the next day into another freezer (-28 °C). Prior to processing, the pork trim was tempered to 1 °C in a cooler (2 °C) for initial grinding. Grinding took place one day prior to emulsion production. The pork trim was crust frozen in the blast freezer to aid in the grinding process and maintain the temperature at (-1 °C).

The pork trim 50/50 was ground through a 1.27 cm grinder plate. A 5.90 kg sample was randomly taken to determine the fat content using an Anyl Ray Fat Analyzer. The pork trim was then batched into individual treatments according to the required weight in meat lugs. The meat was then placed into the cooler (0 °C) until further processing the next day.

Developing the Frankfurter Base Formulations

The meat block formulation was set at 32.5 percent fat content to establish a target fat content of 27.5 percent in the finished product. The formulations (Table 5.1) for the frankfurters consisted of lean pork (picnic cushion meat – 88/12), pork trim (50/50), ice, water, spice, salt, sodium phosphate, sodium erythorbate, curing salt (6.25 percent sodium nitrite), and the treatment ingredient. The specific treatment ingredients used were chicken collagen, and turkey collagen.

Making the Emulsion

One day prior to processing, a container of ice water was placed in the cooler to equilibrate to approximately 0.5 °C. Emulsions were produced using methods described by Rust (1987). The picnic cushion trim was chopped (Kramer-Grebe bowl chopper, Model VSM65, Wallau/Lahn, Germany) with the salt, curing salt, and half of the ice/water (and treatment addition with the appropriate amount of water per treatment, if required) with a

vacuum until 3 °C was achieved. The sides of the chopper bowl were scraped randomly with a plastic scraper.

After the initial temperature was reached, the chopper blades were turned to a low speed and the bowl was left on low to incorporate the remaining ingredients. The 50/50 pork trim, spices, sodium erythorbate, and the sodium phosphate, which was diluted in the remaining ice/water, were added to the bowl chopper and chopped under vacuum until the temperature reached 14 °C. The emulsion was removed from the chopper and placed into a labeled meat lug. A portion of the emulsion (approximately 4.0 lbs.) was placed in a vacuum bag (Cryovac B540 17.8 x 30.5 cm, Cryovac Division, W.R. Grace & Co., Duncan, SC). The emulsion was then vacuum packaged (with vacuum) using a Multivac double chamber-packaging machine (Model AG800, Multivac, Kansas City, MO). Packaging film had an O_2 transmission rate of 3-6 cc/m^2/24 hr at 1 atm, 4.4 °C, and 0% relative humidity, and a vapor transmission rate of 0.5-0.6 g/645 cm^2/24hr and 100% relative humidity. The vacuum package was then placed in the cooler until it was stuffed.

Procedures between the Treatments

The chopping bowl was rinsed with cold water and dried with paper towels. The plastic scraper and blades were also rinsed with cold water.

Stuffing the Emulsion

The vacuum bag with the emulsion was placed into the stuffer (5 lb. Sausage Stuffer, The Sausage Maker, Buffalo, NY), the tip of the bag was pulled out and cut off with scissors.

Wierbicki Tubes

To determine emulsion stability, the Rongey method (Rongey 1965; Sebranek and others 2001) was used. The 3.175 cm stuffing horn was tightened onto the stuffer. Two

Wierbicki tubes were labeled, weighed, recorded and stuffed with approximately 25 grams of emulsion for each treatment. The emulsion was stuffed by resting the stuffing horn on the glass disc and simultaneously turning the stuffer handle. Some pressure was applied on the emulsion so that it filled the tube without air pockets, while not forcing the emulsion past the glass disc. The Wierbicki tubes were reweighed to determine the actual sample weight. After stuffing, the Wierbicki tubes were placed into the cooler until eight Wierbicki tubes were accumulated for thermal processing.

Cellulose Casings

The majority of the emulsion was placed into the stuffer (Risco stuffer, Model RS 4003-165, Stoughton, MA) and stuffed into a 21-22 mm cellulose casing (Devro-Teepak Wienie-Pak RP 24/10, Westchester, IL), linking the casing to yield approximately eight frankfurters per pound of finished product. The treatments were labeled and drenched with liquid smoke (Supreme Poly liquid smoke, Red Arrow Products Company, Manitowoc, WI) to develop a uniform smoke color on the finished product. The liquid smoke solution consisted of 20 percent Supreme Poly and 80 percent cold water. The frankfurters were drenched for 90 seconds. The raw product was subsequently weighed and recorded to determine yields. The treatments were then randomly placed on a smokehouse truck. After four treatments were placed on the smokehouse truck, it was moved into the smokehouse for thermal processing. Between each treatment the stuffer was disassembled and rinsed with warm water.

Thermal Processing of the Emulsion

Wierbicki Tubes

The Wierbicki tubes were thermal processed in a hot water bath (72 °C) for 30 minutes to achieve an internal temperature of 71 °C. The tubes were then removed from

the hot water bath and allowed to cool for 2-3 minutes. The tubes were then centrifuged at low speed (10,000 rpm) for 5 minutes. The tubes were removed from the centrifuge machine (Model 61, Chicago Surgical and Electrical Co., Chicago, IL) and the amounts of separated fat (top layer) and separated water (bottom layer) were read and recorded. The percent water separation and percent fat separation were determined by the following equations:

Percent water separation = (ml of water / sample weight) x 100

Percent fat separation = (ml of fat / sample weight) x 100

Percent total liquid separation = % water separation + % fat separation

Cellulose Casings

Thermal processing of the cellulose casing samples (frankfurter samples) were done using an Alkar thermal processing unit (Model MT EVD RSE 4, Alkar Engineering Corp., Lodi, WI). The thermal processing schedule accommodated the drenching of the raw product to develop exterior smoke color. The final internal temperature of the product was brought to 71 °C using the cooking schedule in Table 5.2.

The smoke house truck was then covered with a plastic combo liner and moved into the finished product cooler (2 °C). The following day, the cellulose casing samples were reweighed to determine the cold yield using the following equation:

Percent smokehouse yield = (cold cooked weight / raw weight) x 100

A Townsend Engineering peeler (Model 260, Townsend Engineering, Des Moines, IA) was used to peel the frankfurters prior to packaging. The treatments were then packaged in vacuum bags (Cryovac B540), vacuum packaged, and heat shrunk. The frankfurters were then boxed, returned to the cooler (2 °C) and held for further analysis.

Chemical Analysis (Fat, Moisture, and Protein)

Fat, moisture, and protein determinations were performed for each replication using the Soxhlet apparatus (hexane extraction) (AOAC 1990a), gravity oven drying (AOAC 1990b), and combustion method (AOAC 1993), respectively. For each treatment, measurements were made in duplicate. Ash was determined by adding the fat, moisture, and protein values together and subtracting the total from 100.

Color Analysis

Instrumental color analysis was conducted to determine internal color. Color readings were taken using a Hunterlab Labscan instrument (Model LS, 1500, Reston, VA). Color readings evaluated CIE L* (lightness), a* (redness/greenness) and b* (yellowness/blueness). A port size of 1.27 cm was used with the A illuminant light source and a 10° standard observer. Calibrations were conducted after covering the calibration plates with the Saran film. Tube samples and frankfurters were sliced in half longitudinally. The samples were then covered with Saran film and readings were taken through the Saran film. Two readings were taken per sample (e.g. tube or frankfurter) and three samples were measured, giving a total of six measurements per treatment.

Purge Analysis

Purge loss was measured on duplicate samples. The weight of the packages (6 frankfurters/package) was taken on day 1 (one day after packaging), day 7, day 14, day 21, and day 28 for each replication. On the appropriate day, the packages (containing the frankfurters) were weighed, opened, drained, and the packaging material was blotted dry. The frankfurter and packaging material were then reweighed to determine the weekly purge loss. Purge loss was calculated by the following equation:

Percent = 100 - ((frankfurter weight + dried package weight) / initial package weight) x 100
purge loss

Texture Analysis

Puncture Test

The puncture test was selected because it measures the force required to push a punch or probe into a food. Texture was determined using the TA.XT2i Texture Analyzer (Texture Technologies Corp., Scarsdale, NY). The texture analyzer was calibrated using a 5 kg weight prior to texture measurement. Sample identification numbers were entered into the computer and a 3 mm diameter stainless steel puncture probe (TA-52) was used.

The 3 mm probe was programmed to penetrate 12 mm into each sample after the TA.XT2i detects the sample's surface at 12 grams of resistance. The penetration was 1.5 mm/second. The pre-test speed was 3.0 mm/second and the post-test speed was 10.0 mm/second. Samples were tested at room temperature (one hour after being removed from refrigeration) to ensure consistency between treatments. No tests were conducted within the last 1.27 inch of the end of the sample.

Samples were measured for penetration peak force and average interior firmness. The peak force was determined to be the force required to break the outer surface or skin (exterior firmness) of the sample. The average interior firmness was the force required to penetrate each sample between 6.0 mm and 10.0 mm peak force of penetration. For each treatment, two readings were taken per sample and three samples were measured giving a total of six measurements per treatment.

Two-Compression Test

The TA.XT2i Texture Analyzer was also used to determine the texture profile analysis of samples by a two-compression test illustrated by Bourne (1978) and Steffe (1996). The sample was cut to yield a 2.54 cm cylinder. The TA.XT2i Texture Analyzer was calibrated

with a 5 kg weight and Texture Expert software was used. The test was performed at 3.3 mm per second with a 12.7 mm compression (50 percent) on one sample and a 18 mm compression (72 percent) on a second sample. Two compression quantities (50 percent and 72 percent) were used. A 5 gm change in force was set to signal that the sample was present. A TA-4 (40 mm cylinder) was used and the computer was set to acquire 200 points per second during the experiment. Samples were measured for cohesiveness, chewiness, springiness, hardness (first bite). One reading was taken per sample and the experiment was conducted in triplicate.

Sensory Evaluation of Texture

The appropriate forms were completed and submitted to the Iowa State University Institutional Review Board prior to the training of the sensory panels. Panelists for texture evaluation were recruited from the faculty, staff, and students in the Department of Food Science and Human Nutrition at Iowa State University. A ten-member trained sensory panel was used to evaluate the texture characteristics of the treatments. Three one-hour training sessions were held at which time panelists were familiarized with the attributes to be evaluated, the techniques to be used during the evaluation process, and the computer software scoring system. Panelists were trained by using commercial products selected to exhibit a range of the intensity of the attributes being evaluated. The sensory evaluation utilized several descriptive terms the panelist were trained to use during initial panel preparation. These descriptive terms for each attribute are outlined in Table 5.3, and the scoring scale sheet is outlined in Figure 5.1.

Attributes were measured using a line scale (numerical value of 15 units) for each of the parameters with descriptive anchors indented 0.5 units from each end of the line. Data was collected using a computerized sensory system (COMPUSENSE five, V4.0, Compusense,

Inc., Guelph, Ontario, Canada). Frankfurters were placed in a two-quart saucepan containing water that had been brought to a boil. The pan was then covered and removed from the heat and held for seven minutes. The ends of the heated frankfurters were discarded and the remaining portion was cut into 1.3 cm long pieces. Each panelist received pieces from a single frankfurter in a covered four-ounce polyfoam container labeled with a random three-digit code. Samples were served at room temperature. Frankfurters were evaluated in three sessions and for each session, cooking and cutting orders were randomized (American Society for Testing and Materials 1988).

Testing was conducted in partitioned booths under fluorescent lighting conditions. Panelists were provided with water and saltine-type crackers (unsalted tops) and allowed to re-taste. For several of the attributes, a sample with a designated value was available if the panelist wished to use it as a reference during the test. The sample presentation order was randomized for each panelist.

Consumer Sensory Evaluation

Consumer acceptance was determined by asking the 75 participants to indicate their overall opinion of the samples by using a 9-point horizontal category scale for liking/disliking (Figure 5.2). Each participant received $5 as a reward for participating in the study. The participants were 18 years of age or older and were recruited by notifying occupants of campus buildings of the test by e-mail. Individuals who were trained sensory panelists were excluded from the study. Participants were asked to answer three multiple choice demographic/product usage questions relating to age, gender, and frequency with which frankfurters were consumed.

Frankfurters were heated by placing them for seven minutes in a covered two-quart saucepan containing water that had been brought to a boil. After the frankfurters were placed in the boiling water, the saucepan was removed from the heat source. The frankfurters from the five treatments were held at 60 °C in covered glass casserole dishes in convection ovens until being served. The frankfurters were cut into 2.5 cm pieces and participants received a single piece of frankfurter from every treatment. The warm samples were served in covered four-ounce polyfoam containers labeled with random three-digit codes. Cooking and serving orders were randomized.

Participants completed the test by using a computerized scoring system (Compusense five, v 4.4, Compusense, Inc., Guelph, Ontario, Canada). Participants were instructed to rinse their mouth with water before starting to taste and between samples. Samples were evaluated in partitioned booths under fluorescent lighting conditions. All participants evaluated all of the treatments.

Experimental Design and Data Analysis

The study was a 2 (source of collagen) x 2 (amount of collagen) factorial design with a control and three replications. Data was subjected to analysis using the General Linear Model (SAS 2001) to evaluate the effect of treatments on processing parameters, proximate parameters, puncture parameters, texture parameters, color parameters, and purge. When treatment effects were significant ($P<0.05$) least squares means were separated using the Bonferroni adjusted p-value method in which the original p-value was multiplied by the number of comparisons made (e.g. 4 comparisons were made to the control) (Rao 1998.).

Results and Discussion

Yield, Water Separation, and Fat Separation

The least squares means for smokehouse yield are shown in Table 5.4. None of the smokehouse yields from the poultry collagen treatments were statistically significant ($P>0.05$). In general, these data agree with the suggestion made by Prabhu (2003) that the collagens immobilize free water and prevent moisture loss during heat processing. On the other hand, Jones (1984) stated that collagen and connective tissue play an important role in comminuted meat products by altering product yield. This was reinforced by Eilert and Mandigo (1993) who reported declined processing yield losses with the addition of desinewed connective tissue form beef hind shank meat.

The least squares means for water and fat separation are displayed in Table 5.5. The percent water separation for the 1 percent chicken and turkey collagen treatments were not significantly different ($P>0.05$) from the control, whereas the 2 percent chicken and turkey collagens resulted in significantly higher ($P<0.05$) water separation percentages when compared to the control. These results are inconsistent when comparing the percent water separation to the smokehouse yield and percentage of moisture in the final product (discussed in the next section). This inconsistency is most likely to be due to the difference in cooking methods (e.g. 71 °C water bath versus smokehouse). There were no significant differences ($P>0.05$) in the percentage of fat separation of the treatments compared to the control. , which is consistent with Bonifer and others (1996).

Proximate Composition

The least squares means for proximate composition are shown in Table 5.6. The 2 percent chicken collagen was the only treatment that resulted in a significantly ($P<0.05$) higher moisture content when compared to the control. All other poultry collagen

treatments were not significantly (P>0.05) different from the control. These results are comparable to the results of the smokehouse yield data. Since the smokehouse yields were higher for the poultry collagen treatments than the control, it was expected that moisture content of the frankfurters would follow the same pattern.

The percentage fat, and protein were not statistically significant (P>0.05). Acton and Dick (1978) reported that the use of poultry skin resulted in a higher fat content in the final product. The author's conclusion is not comparable to this study due to the differences between the poultry collagen utilized in the research projects. Acton and Dick (1978) used raw poultry skin whereas this study utilized processed poultry skins. Although Acton and Dick (1978) did not report the proximate composition of the poultry skin utilized in their experiment, Bonifer and others (1996) reported that unwashed chicken skin had 41 percent fat, 8 percent protein, 46 percent moisture, and .5 percent ash. The chicken collagen used in this study consisted of 70 percent protein, 28 percent fat, and 1.5 percent moisture; while the turkey collagen consisted of 77 percent protein, 20 percent fat, and 2 percent moisture. Due to the high protein and low-fat content of the collagens, the percentage of fat in the poultry treatments decreased. Furthermore, by removing a portion of the lean and replacing it with poultry collagen and water in the formulation, the protein content in the poultry collagen treatments were comparable to the control.

Color Analysis

The least squares means for interior CIE L* (lightness), a* (redness/greenness), and b* (yellowness/blueness) are shown in Table 5.7. Treatment CIE L* and a* values were not significantly (P>0.05) different from the control. These results are not consistent with Bonifer and others (1996). Bonifer and others (1996) reported that increased additions (0, 10, and 20 percent) of washed chicken skin resulted in significantly (P<0.05) increased

Hunter L and decreased Hunter a_L values. It can be concluded from the CIE L* results of this experiment that even though a portion of the lean, which contained a majority of the color component (myoglobin) was removed, the interior lightness was not affected. The difference in results is due to the amounts of chicken skin added compared to our experiment. The CIE b* values for the turkey collagen treatments were significantly ($P<0.05$) higher than the control. The turkey treatments resulted in a frankfurter with a more yellow interior color. These CIE b* results are contrary to the results of Bonifer and others (1996) who reported a less yellow product due to the addition of washed chicken skin.

Purge Analysis

The least squares means for percent purge are shown in Table 5.8. Although the 1 and 2 percent poultry collagen treatments had a higher percentage of purge when compared to the control, none of the treatments were significantly ($P>0.05$) different from the control. Past research has shown that purge of frankfurters was not altered due the replacement of a portion of the lean with collagen (Delmore and Mandigo 1994). Osburn and Mandigo (1998) reported the same trend of a slight in increase in purge due to the addition of collagen. Research by Prabhu (2003) resulted in controlled purge of turkey smoke sausage when 5 percent of the turkey thigh meat was replaced with 1 percent turkey collagen and 4 percent water.

Puncture Analysis

The least squares means for peak force (gm of force) and internal force (gm of force) are shown in Table 5.9. The 2 percent turkey collagen treatment was the only treatment that was significantly ($P<0.05$) lower in peak force and internal force when compared to the control. Overall, all other poultry collagen treatments had a lower peak

force and internal force than the control. The lower peak force and internal force may relate to smokehouse yields and the amount of amount of moisture in the final product. As discussed previously, all poultry collagen treatments had a higher smokehouse yield and moisture content when compared to the control. The higher smokehouse yields results in less tough exterior skin on the frankfurters and the higher moisture content creates a softer interior.

Texture Profile Analysis

The least squares means for cohesiveness, chewiness (gm of force), springiness (mm of distance), and hardness (gm of force) are shown in Table 5.10. None of the texture characteristics measured were statistically significant ($P>0.05$). These results are consistent with Bonifer and others (1996) who reported that the addition of chicken skin did not affect the compression measurements of hardness, springiness, cohesiveness, and chewiness when compared to a control with no added skin.

Sensory Evaluation of Texture

The least squares means for cohesiveness, chewiness, springiness, hardness, and skin toughness are shown in Table 5.11. The 2 percent turkey collagen treatment was the only treatment that was significantly ($P<0.05$) lower in cohesiveness when compared to the control. The 2 percent collagen treatments displayed significantly ($P<0.05$) less chewiness when compared to the control, while the 1 percent collagen treatments were not significantly ($P>0.05$) different from the control. Although Jones and others (1982) used a different collagen source, the authors also concluded that higher collagen content in the formulation leads to lower chewiness scores. The springiness of all poultry collagen treatments were significantly ($P<0.05$) lower than the control. The hardness of the chicken collagen treatments were not significantly ($P>0.05$) different than the control, while the

turkey collagen treatments were significantly ($P<0.05$) lower in hardness when compared to the control. In general, all poultry collagen treatments had lower hardness values than the control. This is consistent with Osburn and others (1999) who determined that the incorporation of desinewed beef connective tissue gels in reduced-fat bologna decreased product hardness. The 2 percent turkey collagen treatment was the only treatment that was significantly ($P<0.05$) lower in skin toughness when compared to the control. The toughness of all other treatments were not significantly ($P<0.05$) different from the control. The juiciness characteristic was not statistically significant ($P>0.05$) (data not shown).

Consumer Acceptance Evaluation

Due to statistical differences in texture characteristics revealed by the trained sensory panel, it was determined that a consumer acceptance evaluation should be conducted to determine if those differences would affect consumer acceptance of the frankfurters. The least squares means for consumer acceptance are shown in Table 5.12. The 2 percent turkey collagen treatment was significantly ($P<0.05$) less acceptable when compared to the control. Trained sensory data previously mentioned indicated that the 2 percent turkey collagen treatment was consistently lower than all other treatments and the control within each texture parameter. The acceptance scores for all other treatments were not significantly ($P>0.05$) different from the control.

A majority of the results were consistent with Schnell and others (1973) and Delmore and Mandigo (1994). Schnell and others (1973) concluded that chicken skin did not adversely affect the overall acceptability of the finished product. Delmore and Mandigo (1994) reported no difference in overall acceptability between frankfurters containing 0 and 10 percent pork sinew.

Conclusions

High costs of raw materials have made it highly desirable to reassess the potential for making edible and attractive processed meat products with the use of poultry collagens. Campbell and Kenney (1994) listed poultry skin as generally being a filler ingredient in poultry or mixed-species batter sausages, but this research shows that poultry collagen could be beneficial protein ingredient in frankfurter formulations. The results of this study indicate that poultry collagens can be used in frankfurters to replace a portion of the lean with collagen and water while maintaining processing, analytical, color, and texture characteristics. Smokehouse yields were not statistically significant, proximate composition of the final product was maintained, and purge loss was controlled. Although specific texture differences were observed between the control and the treatments, these differences did not result in a statistical difference in consumer acceptance for most treatments when the treatments were compared to the control. These results indicate that the use of poultry collagens in frankfurter formulations should be considered for production of an economical consumer-acceptable product.

References

[A.O.A.C.] Association of Official Analytical Chemists. 1990a. Fat (crude) or ether extract in meat. In: Official Methods of Analysis, 15th ed. Arlington, VA: AOAC 960.39.

[A.O.A.C.] Association of Official Analytical Chemists. 1990b. Moisture in meat. In: Official Methods of Analysis, 15th ed. Arlington, VA: AOAC 950.46.

[A.O.A.C.] Association of Official Analytical Chemists. 1993. Crude protein in meat and meat products. In: Official Methods of Analysis, 15th ed 4th suppl. Arlington, VA: AOAC 992.15.

Acton JC, Dick RL. 1978. Effect of skin content on some properties of poultry meat loaves. Poultry Sci. 57(5):1255-1259.

Ambrosiadis J, Wirth F. 1984. Comminution of connective tissue and temperature pattern in the manufacture of frankfurter-type sausages. Fleischwirtschaft. 64(8):945-950.

American Society of Testing and Materials. 1988. Standards on Sensory Evaluation of Materials and Products. Storer RC, editor. ASTM Manual series. Philadelphia, PA.

Asghar A, Henrickson RL. 1982. Functional properties of food-grade bovine hide collagen in coarse bologna. II. Effect on different protein fractions. J. Food Quality. 5(4):271-284.

Baker RC, Darfler JM, Vadehra DV. 1968. The effect of level of skin on the quality of chicken frankfurters. Poultry Sci. 47:1989-1996.

Bailey AJ, Light ND. 1989. Connective tissue in meat and meat products. London: Elsevier Appl. Sci. P 225-247.

Bonifer LJ, Froning GW, Mandigo, RW, Cuppett SL, Meagher MM. 1996. Textural, color, and sensory properties of bologna contaning various levels of washed chicken skin. Poultry Sci. 75:1047-1055.

Bourne MC. 1978. Texture profile analysis. Food Technol. 32(7):62-66, 72.

Calhoun CM, Eilert SJ, Mandigo RW. 1996a. Connective tissue/acidic phosphate preblend effects on reduced-fat frankfurters. J. Food Sci. 61(2):459-464.

Calhoun CM, Eilert SJ, Mandigo RW. 1996b. Characteristics of low-fat, high-added-water frankfurters manufactured with preblends of connective tissue and alkaline phosphates. J. Muscle Foods. 7(4):471-487.

Campbell RE, Kenney PB. 1994. Edible by-products for the production and processing of muscle foods. In: Kinsman DM, Kotula AW, Breidenstein BC, editors. Muscle Foods: Meat and Poultry and Seafood Technology. New York, NY: Chapman and Hall. P 79-105.

Carpenter JA, Wiley EL, Reagan JO, Campion DR. 1979. Relationship of collagen content to functional properties of sausage meats. In: Carpenter JA, editor. 21st Proceeding of Meat Science Institute. P 71-74.

Chavez J, Henrick RL, Rao BR. 1985. Collagen as a hamburger extender. J. Food Quality. 8(4):265-272.

Delmore RJ, Mandigo RW. 1994. Modified pork connective tissue for use in low-fat high added water frankfurters [abstract]. In: IFT Annual Meeting Book of Abstracts; 1994 June 25-29; Atlanta, GA. Chicago, IL.: Institute of Food Technologists. Abstract nr 47D-27.

Eilert SJ, Calhoun CM, Mandigo RW. 1996a. Phosphate type, concentration and preblend duration to improve water holding capacity of beef connective tissue. J. Muscle Foods. 7(2):255-269.

Eilert SJ, Mandigo RW, Sumner SS. 1996b. Phosphate and modified beef connective tissue effects on reduced-fat, high water-added frankfurters. J. Food Sci. 61(5):1006-1011, 1029.

Eilert SJ, Mandigo RW. 1993. Procedure for soluble collagen in thermally processed meat products, J. Food Sci. 58(5):948-949.

Fojtik TR. 1997. Utilization of modified pork skin in fresh sausage [MS thesis] University of Nebraska-Lincoln, Lincoln, NE.

Hudspeth JP, May KN. 1969. Emulsifying capacity of salt-soluble proteins of turkey meat. II. Heart, gizzard and skin from broilers, turkeys, hens, and ducks. Food Technol. 23(3):99-100.

Jones KW. 1984. Collagen properties in processed meats. Proceedings of the Meat Industry Research Conference, American Meat Science Association, American Meat Institute, Chicago, Ill. P 18-28.

Jones KW, Snyder WD, Mandigo RW, Calkins CR. 1982. Effects of varying collagen levels on the emulsion properties of sausage batters [abstract]. In: Annual Meeting of the American Society of Animal Science. Guelph, Canada. Abstract nr 307.

Ladwig KM, Knipe CL, Sebranek JG. 1989. Effects of collagen and alkaline phosphate on time of chopping, emulsion stability and protein solubility of finely cut meat systems. J. Food Sci. 54(3):541-544.

Mandigo RW. 1991. Meat processing: The modifications of processed meats. In: Haberstroh C, Morris CE, editors. Fat and Cholesterol Reduced Foods. Woodlands, TX: Portfolio Publishing Co. 119-131.

Marsden JL. 1981. Technological developments in the manufacture of poultry frankfurters. Proc. Recip. Meat Conf. National Live Stock and Meat Board, Chicago, IL.Proc. 34:126-134.

Maurer AJ, Baker RC. 1966. The relationship between collagen content and emulsifying capacity of poultry meat. Poultry Sci. 45(6):1317-1321.

Osburn WN, Mandigo RW. 1998. Reduced-fat bologna manufactured with poultry skin connective tissue gel. Poultry Sci. 77(10):1574-1584.

Osburn WN, Manidgo RW, Eskridge KM. 1997. Pork skin connective tissue gel utilization in reduced-fat bologna. J. Food Sci. 62(16):1176-1182.

Osburn WN, Mandigo RW, Calkins CR. 1999. Utilization of desinewed beef connective tissue gel in reduced-fat bologna. J. Muscle Foods. 10(1):29-50.

Puolanne E, Ruusunen M. 1981. The properties of connective tissue membrane and pig skin as raw materials for cooked sausage. Meat Sci. 5(5):371-382.

Prabhu GR. 2003. Poultry collagen: Ingredients that combine flavor and functionality. Meat and Poultry. January: 68-75.

Prabhu GR, Doerscher DR. 2000. Collagen's new application. Meat and Poultry. April: 65-69.

Quint LN, Mandigo RW, Calkins CR. 1987. Use of pork skin pre-emulsions in a low-fat pork loaf product. Nebraska Swine Report. EC 87-219:22-24. Univ. of Nebraska, Lincoln, NE.

Randall CJ, Raymond DP, Voisey PW. 1976. Effect of various animal and vegetable protein materials on replacing the beef component in a meat emulsion system. Can. Inst. Food Sci. Technol. J. 9(4):216-221.

Rao PV. 1998. Single factor studies: Comparing means and determining sample sizes. In: Statistical Research Methods in the Life Sciences. Pacific Grove, CA: Brooks/Cole Publishing Co. P326-377.

Rao BR, Henrickson RL. 1983. Food grade hide collagen in bologna effect on functional properties, texture and color. J. Food Qual. 6(1):1-10.

Rongey EH. 1965. A simple objective test for sausage emulsion quality. Proc of Meat Ind. Res. Conf. American Meat Institute Foundation, Chicago, IL.

Rust RE. 1987. Sausage products. In: Price JF, Schweigert BS, editors. The Science of Meat and Meat Products, 3rd ed. Westport CT: Food and Nutrition Press, Inc. P 473-485.

Sadler DHN, Young OA. 1993. The effect of preheated tendon as a lean meat replacement on the properties of fine emulsion sausage. Meat Sci. 35(2): 259-268.

Sadowska M, Sikorski AE, Dobosz M. 1980. The influence of collagen on the rheological properties of meat homogenates. Lebensm. -Wiss. u. -Technol. 13(5):232-236.

Saffle RL, Carpenter JA, Moore DG. 1964. Peeling ease of frankfurters. 1. Effect of chemical composition, heat, collagen, and type of fat. Food Technol. 18(12):130-132.

Salvage B. 2002. Doggin' it. Meat Marketing and Technology. December:44-47.

SAS Institute, Inc. 2001. SAS user's guide, version 8.2. SAS Institute. Cary, NC.

Satterlee LD, Zachariah NY, Levin E. 1973. Utilization of beef and pork skin hydrolzates as a binder or extender in sausage emulsions. J. Food Sci. 38(2):268-270.

Schnell PG, Nath KR, Darfler JM, Vadehra DV, Baker, RC. 1973. Physical and functional properties of mechanically deboned poultry meat as used in the manufacture of frankfurters. Poultry Sci. 52:1363-1369.

Sebranek JG, Lonergan SM, King-Brink M, Larson E. 2001. Emulsion evaluations and water holding capacity. In: Meat Science and Processing - 3rd ed. Zenda, WI: Peerage Press. P 134-146.

Smolińska T, Kopeć W, Trziszka T. 1988. Effect of skin addition on the technological properties of comminuted chicken meat emulsions. Int. J. Food Sci. Technol. 23:441-446.

Steffe JF. 1996. Rheological Methods in Food Process Engineering. East Lansing, MI: Freeman Press. P 1-91.

United States Department of Agriculture. 2002. Code of Federal Regulations. Citation 9CFR319.180a (http://www.usda.gov). United States Department of Agriculture. Washington, DC.

Table 5.1. Formulations for pork emulsion from control and experimental Frankfurters formulated with a portion of lean replaced by various protein ingredients (Batch size: 75 lbs.).

	Control [a]	Treatments	
		1% Treatment [b]	2% Treatment [c]
Ingredient	**%**	**%**	**%**
Pork Lean [d]	40.35	36.35	32.35
Pork Trim [e]	35.15	35.15	35.15
Ice	9.94	9.94	9.94
Water	9.94	9.94	9.94
Spice	2.11	2.11	2.11
Salt	1.82	1.83	1.84
Sodium Phosphate	0.45	0.45	0.45
Sodium Erythorbate	0.0413	0.0391	0.0369
Curing Salt (6.25%) [f]	0.1885	0.1785	0.1685
Treatment	0.00	1.00	2.00
Water for Treatment	0.00	3.00	6.00
	100.00	100.00	100.00

[a] Control = No lean meat replacement, same control was used for 1% and 2% treatments.
[b] 1% Treatment = 4% of the lean meat component in the emulsion formulation was replaced by 1% treatment ingredient and 3% water.
[c] 2% Treatment = 8% of the lean meat component in the emulsion formulation was replaced by 2% treatment ingredient and 6% water.
[d] Pork lean = Pork cushion (88/12) purchased from Iowa Packing Company (Des Moines, IA).
[e] Pork trim = Pork trim (50/50) purchased from Iowa State University Meat Laboratory (Ames, IA).
[f] Curing salt (6.25%) = Contains 6.25% sodium nitrite and 93.75% salt.

Table 5.2. Cooking schedule for frankfurters from control and experimental frankfurters formulated with a portion of lean replaced by various protein ingredients.

Step Type	Step Time	Dry Bulb (°C)	Wet Bulb (°C)	RH [a] (%)	IT [b] (°C)	Main Blower
Cook	00:10:00	43	38	70	-------	4
Cook	00:30:00	63	38	21	-------	10
Cook	00:30:00	63	38	21	-------	2
Cook	00:15:00	68	0	0	-------	7
Steam Cook	00:01:00	82	82	100	71	1
Cold Shower	00:15:00	10	10	0	-------	0

[a] RH = Relative humidity of the smokehouse.
[b] IT = Internal temperature of the frankfurter.

Table 5.3. Description of terms, techniques for texture evaluation, labels for anchors, commercial product references and texture reference value used for training sensory panelists as measured by using a line scale (numerical value of 15 units) with descriptive anchors for each of the texture parameters.

Term	Technique for Texture Evaluation	Label for 0	Label for 15	References and Values
Toughness of exterior	Place the sample between the incisors so that you will be able to bite through the skin. Bite down evenly, and evaluate the force to penetrate through the surface	Very soft	Very tough	Hormel Vienna Sausage Value = 1 Armour Stars Hot Dogs - Original Value = 11
Hardness	Place the sample between your molars as described above, bite down evenly, and evaluate the force to bite completely through the sample.	Very soft	Very hard	Gerber Graduate Meat Sticks Value = 1 Armour Stars Hot Dogs - Original Value = 10
Cohesiveness	Place the sample between your molars as described above, compress it fully and evaluate the degree to which the sample deforms before it ruptures. A sample with high cohesiveness will undergo much deformation before it ruptures. A sample with low cohesiveness ruptures with little deformation.	Not cohesive (little deformation before rupture)	Very cohesive (much deformation before rupture)	Jack Link's Original Beef Stick Value = 1

Term	Technique	Label for 0	Label for 15	Reference and Values
Springiness	Place the sample between your molars, with the cut edges adjacent to the surface of the molars. Compress partially without breaking, release, and evaluate the degree to which the sample returns to its original shape.	Not springy	Very springy	Gerber Graduate Meat Sticks Value = 1 Hormel Fat-Free Beef Hot Dogs Value = 10
Chewiness	The amount of chewing required to prepare the sample for swallowing.	Not chewy	Very chewy	Gerber Graduate Meat Sticks Value = 2 Armour Stars Hot Dogs - Original Value = 9
Juiciness	The progressive increase in the sensation of moisture in the mouth during chewing	Not juicy	Very juicy	No Reference

Table 5.4. Least squares means for smokehouse yields (%) from control and experimental frankfurters formulated with a portion of lean replaced by poultry protein ingredients.

Treatment	Smokehouse Yield (%) [a]
Control [b]	90.8
Chicken Collagen – 1% [c]	91.2
Chicken Collagen – 2% [d]	91.1
Turkey Collagen – 1% [c]	91.2
Turkey Collagen – 2% [d]	90.9
SEM [e]	0.41

[a] Smokehouse yield = Percent cold yield = (cold cooked weight / raw weight) x 100.
[b] Control = No lean meat replacement, same control was used for 1% and 2% treatments.
[c] 1% Treatment = 4% of the lean meat component in the emulsion formulation was replaced by 1% treatment ingredient and 3% water.
[d] 2% Treatment = 8% of the lean meat component in the emulsion formulation was replaced by 2% treatment ingredient and 6% water.
[e] SEM = Standard error of the means for the smokehouse yield values of the control and experimental frankfurters.

Table 5.5. Least squares means for water separation (%) and fat separation (%) from control and experimental samples formulated with a portion of lean replaced by various poultry protein ingredients, as measured with a Rongey (1965) method.

Treatment	Water Separation (%) [a]	Fat Separation (%) [b]
Control [c]	3.05 [g]	0.60 [g]
Chicken Collagen – 1% [d]	3.19 [g]	0.48 [g]
Chicken Collagen – 2% [e]	4.30 [h]	0.78 [g]
Turkey Collagen – 1% [d]	3.97 [g]	0.70 [g]
Turkey Collagen – 2% [e]	4.22 [h]	0.83 [g]
SEM [f]	0.27	0.08

[a] Water separation = Percent water separation = (ml of water / sample weight) x 100.
[b] Fat separation = Percent fat separation = (ml of fat / sample weight) x 100.
[c] Control = No lean meat replacement, same control was used for 1% and 2% treatments.
[d] 1% Treatment = 4% of the lean meat component in the emulsion formulation was replaced by 1% treatment ingredient and 3% water.
[e] 2% Treatment = 8% of the lean meat component in the emulsion formulation was replaced by 2% treatment ingredient and 6% water.
[f] SEM = Standard error of the means for the water and fat seperation values of the control and experimental samples.
[gh] Means within the same column with different superscripts are different from the control ($P<0.05$). Significant main effects were separated using the Bonferroni adjusted p-value method for multiple comparisons.

Table 5.6. Least squares means for moisture (%), fat (%), protein (%), and ash (%) from control and experimental frankfurters formulated with a portion of lean replaced by various poultry protein ingredients, as measured by AOAC methods [a].

Treatment	Moisture (%)	Fat (%)	Protein (%)	Ash (%)
Control [b]	57.0 [f]	25.3	12.7	5.0
Chicken Collagen – 1% [c]	57.7 [f]	24.7	12.7	5.0
Chicken Collagen – 2% [d]	58.6 [g]	23.8	13.0	4.6
Turkey Collagen – 1% [c]	57.9 [f]	24.6	12.7	4.8
Turkey Collagen – 2% [d]	57.7 [f]	25.0	12.5	4.8
SEM [e]	0.34	0.62	0.20	0.24

[a] AOAC methods = Moisture was measured using the AOAC (1990b) method – Moisture in meat.
Fat was measured using the AOAC (1990a) method – Fat (crude) or ether extract in meat.
Protein was measured using the AOAC (1993) method – Crude protein in meat and meat products.
Ash was determined by adding the fat, moisture, and protein values together and subtracting the total from 100.

[b] Control = No lean meat replacement, same control was used for 1% and 2% treatments.

[c] 1% Treatment = 4% of the lean meat component in the emulsion formulation was replaced by 1% treatment ingredient and 3% water.

[d] 2% Treatment = 8% of the lean meat component in the emulsion formulation was replaced by 2% treatment ingredient and 6% water.

[e] SEM = Standard error of the means for the moisture, fat, protein, and ash values of the control and experimental frankfurters.

[fg] Means within the same column with different superscripts are different from the control ($P<0.05$). Significant main effects were separated using the Bonferroni adjusted p-value method for multiple comparisons.

Table 5.7. Least squares means for CIE L* (lightness), a* (redness/greenness), and b* (yellowness/blueness) from control and experimental frankfurters formulated with a portion of lean replaced by various poultry protein ingredients, as measured by a Hunterlab Labscan instrument (Model LS, 1500).

Treatment	L* (lightness)	a* (redness/greenness)	b* (yellowness/blueness)
Control [a]	73.8 [e]	15.8 [e]	15.8 [e]
Chicken Collagen – 1% [b]	73.4 [e]	15.8 [e]	16.2 [e]
Chicken Collagen – 2% [c]	73.4 [e]	15.4 [e]	16.6 [e]
Turkey Collagen – 1% [b]	73.5 [e]	15.1 [e]	16.7 [f]
Turkey Collagen – 2% [c]	73.1 [e]	15.2 [e]	16.9 [f]
SEM [d]	0.41	0.29	0.19

[a] Control = No lean meat replacement, same control was used for 1% and 2% treatments.
[b] 1% Treatment = 4% of the lean meat component in the emulsion formulation was replaced by 1% treatment ingredient and 3% water.
[c] 2% Treatment = 8% of the lean meat component in the emulsion formulation was replaced by 2% treatment ingredient and 6% water.
[d] SEM = Standard error of the means for the CIE L*, a*, and b* values of the control and experimental frankfurters.
[ef] Means within the same column with different superscripts are different from the control ($P<0.05$). Significant main effects were separated using the Bonferroni adjusted p-value method for multiple comparisons.

Table 5.8. Least squares means for pork emulsion purge (%) from control and experimental frankfurters formulated with a portion of lean replaced by poultry protein ingredients as measured on day 1 (one day after packaging), day 7, day 14, day 21, and day 28 for each replication

Treatment	Purge (%) [a]
Control [b]	0.87 [f]
Chicken Collagen – 1% [c]	0.96 [f]
Chicken Collagen – 2% [d]	0.99 [f]
Turkey Collagen – 1% [c]	1.05 [f]
Turkey Collagen – 2% [d]	1.05 [f]
SEM [e]	0.05

[a] Percent purge = 100-((frankfurter weight + dried package weight)/initial package weight) x 100
[b] Control = No lean meat replacement, same control was used for 1% and 2% treatments.
[c] 1% Treatment = 4% of the lean meat component in the emulsion formulation was replaced by 1% treatment ingredient and 3% water.
[d] 2% Treatment = 8% of the lean meat component in the emulsion formulation was replaced by 2% treatment ingredient and 6% water.
[e] SEM = Standard error of the means for the purge values of the control and experimental frankfurters.
[f] Means within the same column with different superscripts are different from the control ($P<0.05$). Significant main effects were separated using the Bonferroni adjusted p-value method for multiple comparisons.

Table 5.9. Least squares means for peak force (gm of force) and internal force (gm of force) control and experimental frankfurters formulated with a portion of lean replaced by various poultry protein ingredients, as measured with a TA.XT2i Texture Analyzer (Texture Technologies Corp.).

Treatment	Peak Force (gm of force) [a]	Internal Force (gm of force) [b]
Control [c]	535 [g]	142 [g]
Chicken Collagen – 1% [d]	490 [g]	137 [g]
Chicken Collagen – 2% [e]	463 [g]	130 [g]
Turkey Collagen – 1% [d]	480 [g]	138 [g]
Turkey Collagen – 2% [e]	394 [h]	118 [h]
SEM [f]	30	4.9

[a] Peak force = Force required to break the outer surface or skin of the frankfurter (exterior firmness).

[b] Internal force = Force required to penetrate break the interior of the frankfurter (average interior firmness).

[c] Control = No lean meat replacement, same control was used for 1% and 2% treatments.

[d] 1% Treatment = 4% of the lean meat component in the emulsion formulation was replaced by 1% treatment ingredient and 3% water.

[e] 2% Treatment = 8% of the lean meat component in the emulsion formulation was replaced by 2% treatment ingredient and 6% water.

[f] SEM = Standard error of the means for the peak force and internal force values of the control and experimental frankfurters.

[gh] Means within the same column with different superscripts are different from the control ($P<0.05$). Significant main effects were separated using the Bonferroni adjusted p-value method for multiple comparisons.

Table 5.10. Least squares means for cohesiveness, chewiness (gm of force), springiness (mm of distance), and hardness (gm of force) from control and experimental frankfurters formulated with a portion of lean replaced by various poultry protein ingredients, as measured by a TA.XT2i Texture Analyzer (Texture Technologies Corp.).

Treatment	Cohesiveness [a]	Chewiness (gm of force) [b]	Springiness (mm of distance) [c]	Hardness (gm of force) [d]
Control [e]	0.67	43400	17.0	6590
Chicken Collagen – 1% [f]	0.64	35600	17.2	6420
Chicken Collagen – 2% [g]	0.67	34700	17.1	5900
Turkey Collagen – 1% [f]	0.66	34400	16.9	6430
Turkey Collagen – 2% [g]	0.65	32700	17.2	5550
SEM [h]	0.016	2850	0.23	405

[a] Cohesiveness = The ratio of the positive force area during the second compression to that during the first compression (Area 2/Area 1).
[b] Chewiness = The product of gumminess times cohesiveness times springiness.
[c] Springiness = The distance or length of compression cycle during the second compression.
[d] Hardness = The force at maximum compression during first compression.
[e] Control = No lean meat replacement, same control was used for 1% and 2% treatments.
[f] 1% Treatment = 4% of the lean meat component in the emulsion formulation was replaced by 1% treatment ingredient and 3% water.
[g] 2% Treatment = 8% of the lean meat component in the emulsion formulation was replaced by 2% treatment ingredient and 6% water.
[h] SEM = Standard error of the means for the cohesiveness, chewiness, springiness, and hardness values of the control and experimental frankfurters.

Table 5.11. Least squares means for cohesiveness, chewiness, springiness, hardness, and skin toughness from control and experimental frankfurters formulated with a portion of lean replaced by various poultry protein ingredients, as measured by a trained sensory panel using a line scale (numerical value of 15 units) for each of the parameters with descriptive anchors.

Treatment	Cohesiveness [a]	Chewiness [b]	Springiness [c]	Hardness [d]	Skin Toughness [e]
Control [f]	7.8 [j]	8.4 [j]	10.7 [j]	9.3 [j]	11.6 [j]
Chicken Collagen – 1% [g]	7.4 [j]	7.4 [j]	9.2 [k]	7.4 [j]	10.3 [j]
Chicken Collagen – 2% [h]	7.5 [j]	6.7 [k]	8.5 [k]	7.5 [j]	11.0 [j]
Turkey Collagen – 1% [g]	7.6 [j]	7.2 [j]	8.8 [k]	7.2 [k]	10.3 [j]
Turkey Collagen – 2% [h]	6.2 [k]	5.4 [k]	7.6 [k]	5.7 [k]	9.2 [k]
SEM [i]	0.32	0.32	0.34	0.42	0.34

[a] Cohesiveness = The degree to which the frankfurter deforms before it ruptures.
[b] Chewiness = The amount of chewing required to prepare the frankfurter for swallowing.
[c] Springiness = The degree to which the frankfurter returns to its original shape.
[d] Hardness = The force to bite completely through the frankfurter.
[e] Toughness = The force to required to penetrate through the surface of the frankfurter.
[f] Control = No lean meat replacement, same control was used for 1% and 2% treatments.
[g] 1% Treatment = 4% of the lean meat component in the emulsion formulation was replaced by 1% treatment ingredient and 3% water.
[h] 2% Treatment = 8% of the lean meat component in the emulsion formulation was replaced by 2% treatment ingredient and 6% water.
[i] SEM = Standard error of the means for the cohesiveness, chewiness, springiness, hardness, and toughness values of the control and experimental frankfurters.
[jk] Means within the same column with different superscripts are different from the control ($P<0.05$). Significant main effects were separated using the Bonferroni adjusted p-value method for multiple comparisons.

Table 5.12. Least squares means for consumer acceptance from control and experimental frankfurters formulated with a portion of lean replaced by various poultry protein ingredients, as measured by a consumer sensory panel using a 9-point horizontal category scale [a].

Treatment	Consumer Opinion
Control [b]	6.4 [f]
Chicken Collagen – 1% [c]	6.5 [f]
Chicken Collagen – 2% [d]	6.6 [f]
Turkey Collagen – 1% [c]	6.2 [f]
Turkey Collagen – 2% [d]	5.5 [g]
SEM [e]	0.18

[a] 9-point horizontal category scale = The category labels were "1=dislike extremely, 2=dislike very much, 3=dislike moderately, 4=dislike slightly, 5=neither like nor dislike, 6=like slightly, 7=like moderately, 8=like very much, and 9=like extremely."

[b] Control = No lean meat replacement, same control was used for 1% and 2% treatments.

[c] 1% Treatment = 4% of the lean meat component in the emulsion formulation was replaced by 1% treatment ingredient and 3% water.

[d] 2% Treatment = 8% of the lean meat component in the emulsion formulation was replaced by 2% treatment ingredient and 6% water.

[e] SEM = Standard error of the means for the consumer opinion values of the control and experimental frankfurters.

[fg] Means within the same column with different superscripts are different from the control ($P<0.05$). Significant main effects were separated using the Bonferroni adjusted p-value method for multiple comparisons.

Figure 5.1. Sensory evaluation score sheet used to measure texture characteristics of control and experimental frankfurters formulated with a portion of lean replaced by various poultry protein ingredients, as measured by using a line scale (numerical value of 15 units) with descriptive anchors for each of the texture parameters.

Date _____
ID _____
Sample Code _____

Please make a horizontal mark on each line to indicate your perception of the textural attributes of the sample.

Toughness: Place the sample between the incisors so that you will be able to bite through the skin. Bite down evenly, and evaluate the force to penetrate through the surface

Very soft — Very tough

Hardness: Place the sample between your molars as described above, bite down evenly, and evaluate the force to bite completely through the sample.

Very soft — Very hard

Cohessiveness: Place the sample between your molars as described above, compress it fully and evaluate the degree to which the sample deforms before it ruptures. A sample with high cohesiveness will undergo much deformation before it ruptures. A sample with low cohesiveness ruptures with little deformation.

Not cohesive — Very cohesive

Springiness: Place the sample between your molars, with the cut edges adjacent to the surface of the molars. Compress partially without breaking, release, and evaluate the degree to which the sample returns to its original shape.

Not springy — Very springy

Chewiness: Place sample between molars and evaluate the amount of chewing required to prepare the sample for swallowing.

Not chewy — Very chewy

Juciness: The progressive increase in the sensation of moisture in the mouth during chewing

Not juicy — Very juicy

Figure 5.2. Consumer sensory evaluation score sheet used to measure consumer acceptance of control and experimental frankfurters formulated with a portion of lean replaced by various poultry protein ingredients, as measured by a using a 9-point horizontal category scale.

Date _____

Registration Code _____

Please answer all questions. Your name is not on the questionnaire and will not be identified with your answers.

1. What is your age?

18-24 _____
25-34 _____
35-44 _____
45-54 _____
55-64 _____
>64 _____

2. What is your gender?

male _____
female _____

3. How often do you typically consume frankfurters?

once a week or more _____
at least once a month _____
a few times per year _____
only rarely_____
never_____

Please rinse your mouth with water before starting the test. Choose the numbered container listed first on the ballot. Open the container and taste the sample. Indicate your overall opinion of the sample. Rinse your mouth with water again and proceed to the next sample listed on the ballot. Repeat the process until you have evaluated all of the samples.

Code Number _____

dislike extremely	neither like or dislike	like extremely

Comments: _____

_____

_____

CHAPTER 6. GENERAL CONCLUSION

The meat processing industry is constantly striving to utilize more of the meat animal. The use of non-skeletal tissues goes a long way towards satisfying needs such as cost containment, raw material balance, and final product quality characteristics. By comparison of Phase 1 and Phase 2 of this research, it was evident that use of all non-meat ingredients (e.g. phosphate, sodium erythorbate, and spices) is necessary in the production of emulsion-type products.

The Rongey method may be an effective tool to study the effect of various binders in meat emulsion systems on water and fat holding capacity, but the results are not conclusive enough to draw inference on smokehouse yields. It was discovered that the TA.XT2i Texture Analyzer measurements resulted in large variations between repeated measures as well as replications. In the future, it is my recommendation that more measurements and/or more replication may be needed to reduce the variability between repeated measures and replications.

Instead of applying classical testing of the null hypothesis for determining differences between the treatments and the control, equivalence testing proved to be an effective statistical tool. The results from frankfurter treatments indicate that the utilization of this lean meat replacement processing technology will yield frankfurters with many attributes equivalent to frankfurters with no lean replacement. The results from the parameters measured in the model emulsion system did not correlate to the results obtained in the frankfurter system. These differences are most likely due to differences between the processing (chopping) systems and thermal processing utilized. Although no correlation existed, this is not evidence that the uses of model emulsion systems are not beneficial. The model system may still be useful in a laboratory table-top product

development scenario to test newly developed functional protein ingredients against functional protein ingredients that are currently being utilized.

The comparison of the poultry collagen treatments to the control resulted in conclusive evidence that these meat proteins are an effective lean meat replacement ingredient and should be considered in the commercial production of frankfurters. At the replacement levels studied, both types of poultry collagens (chicken and turkey) used created minimal differences in proximate composition and had no significant ($P>0.05$) effect on L* values, a* values, and purge when compared to the control. The smokehouse yields and a majority of the proximate composition parameters measured were not shown to be statistically significant. None of the treatment purge values were significantly different from the control ($P<0.05$). Although specific texture differences were revealed between the control and the treatments, it did not create a statistical difference in consumer acceptance within a majority of the treatments when the treatments were compared to the control.

As frankfurter production and sales continue to increase, non-traditional raw materials such as skin collagens need to be considered in an attempt to increase profits without compromising final product quality characteristics. Depending on protein ingredient and replacement level utilized, these results would indicate that the use of protein ingredients such as pork, chicken, and turkey skin collagens to replace a portion of the lean in frankfurter formulations should be considered for the production of an economical consumer-acceptable product.

APPENDICES

LIST OF APPENDICES

Appendix 1: Subjective Color Measurement

National Pork Producers Council 1999. Color, texture, exudation; color standards, and marbling standards. Pork Quality Standards. National Pork Board. Des Moines, IA.

Subjective Color

1. Evaluate ham muscles (ham *semimembranosous*) using Pork Quality Standards (1999).

   Color was evaluated using a scale of 1 to 6 with:
   1 = pale pinkish gray to white
   2 = grayish pink
   3 = reddish pink
   4 = dark reddish pink
   5 = purplish red
   6 = dark purplish red

Replication 1

Positive Control [a]

Meat Block (gm) 1132.5

Meat	Composition [b]	Fat	% Fat [c]		% of Meat Needed	Meat Needed (decimal)	Meat Needed (gm)	Meat
Pork Lean [d]	89.9 lean 10.1 fat	10.1		54.7	70.95	0.7095	803.55	**Pork Lean**
			32.5					
Pork Fat [e]	12.8 lean 87.2 fat	87.2		22.4	29.05	0.2905	328.95	**Pork Fat**
				77.1	100		1132.5	

[a] Control = Fat determination used as a baseline for all formulations.
[b] Composition = Anyl Ray Fat Analyzer (Kartrig Pak, Model 316-48) was used to determine the exact lean and fat content.
[c] % Fat = Formulated for 32.5% fat content in the meat block and targeted fat content of 27.5% fat content in the final product.
[d] Pork lean = Ham *semimembranosous* purchased from Swift and Company (Marshalltown, IA) and trimmed practically free of all visible fat.
[e] Pork fat = Pork backfat purchased from Iowa State University Meat Laboratory (Ames, IA) .

Replication 2

Positive Control [a]

Meat Block (gm) 1132.5

Meat	Composition [b]	Fat	% Fat [c]		% of Meat Needed	Meat Needed (decimal)	Meat Needed (gm)	Meat
Pork Lean [d]	91.8 lean 8.2 fat	8.2		53.7	68.85	0.6885	779.70	**Pork Lean**
			32.5					
Pork Fat [e]	13.8 lean 86.2 fat	86.2		24.3	31.15	0.3115	352.80	**Pork Fat**
				78.0	100		1132.5	

[a] Control = Fat determination used as a baseline for all formulations.
[b] Composition = Anyl Ray Fat Analyzer (Kartrig Pak, Model 316-48) was used to determine the exact lean and fat content.
[c] % Fat = Formulated for 32.5% fat content in the meat block and targeted fat content of 27.5% fat content in the final product.
[d] Pork lean = Ham *semimembranosous* purchased from Swift and Company (Marshalltown, IA) and trimmed practically free of all visible fat.
[e] Pork fat = Pork backfat purchased from Iowa State University Meat Laboratory (Ames, IA) .

Replication 3

Positive Control [a]

Meat Block (gm) 1132.5

Meat	Composition [b]	Fat	% Fat [c]		% of Meat Needed	Meat Needed (decimal)	Meat Needed (gm)	Meat
Pork Lean [d]	90.1 lean 9.9 fat	9.9		61.0	72.97	0.7297	826.35	**Pork Lean**
			32.5					
Pork Fat [e]	6.5 lean 93.5 fat	93.5		22.6	27.03	0.2703	306.15	**Pork Fat**
				83.6	100		1132.5	

[a] Control = Fat determination used as a baseline for all formulations.
[b] Composition = Anyl Ray Fat Analyzer (Kartrig Pak, Model 316-48) was used to determine the exact lean and fat content.
[c] % Fat = Formulated for 32.5% fat content in the meat block and targeted fat content of 27.5% fat content in the final product.
[d] Pork lean = Ham *semimembranosous* purchased from Swift and Company (Marshalltown, IA) and trimmed practically free of all visible fat.
[e] Pork fat = Pork backfat purchased from Iowa State University Meat Laboratory (Ames, IA) .

Replication 1

Controls

Batch Size = 1500 gm

	Positive Control [a]		Negative Control for 1% [b]		Negative Control for 2% [c]	
Ingredient	**%**	**grams**	**%**	**grams**	**%**	**grams**
Pork Lean [d]	53.57	803.55	49.60	744.0	45.60	684.00
Pork Fat [e]	21.93	328.95	21.90	328.5	21.90	328.50
Ice	11.50	172.50	11.50	172.50	11.50	172.50
Water	11.50	172.50	11.50	172.50	11.50	172.50
Salt	1.50	22.50	1.43	21.45	1.35	20.25
Treatment	0.00	0.00	0.00	0.00	0.00	0.00
Water for Treatment	0.00	0.00	4.07	61.05	8.15	122.25
	100.00%	1500.00	100.00%	1500.00	100.00%	1500.00

[a] Positive control = No lean meat replacement, same control was used for 1% and 2% treatments.
[b] Negative control for 1% = 4% of the lean meat component in the emulsion formulation was replaced by 4% water.
[c] Negative control for 2% = 8% of the lean meat component in the emulsion formulation was replaced by 8% water.
[d] Pork lean = Ham *semimembranosous* purchased from Swift and Company (Marshalltown, IA) and trimmed practically free of all visible fat.
[e] Pork fat = Pork backfat purchased from Iowa State University Meat Laboratory (Ames, IA).

Treatments

Batch Size = 1500 gm

	1% Treatment [a]		2% Treatment [b]	
Ingredient	**%**	**grams**	**%**	**grams**
Pork Lean [c]	49.60	744.00	45.60	684.00
Pork Fat [d]	21.90	328.50	21.90	328.50
Ice	11.50	172.50	11.50	172.50
Water	11.50	172.50	11.50	172.50
Salt	1.43	21.45	1.35	20.25
Treatment	1.00	15.00	2.00	30.00
Water for Treatment	3.07	46.05	6.15	92.25
	100.00%	1500.00	100.00%	1500.00

[a] 1% Treatment = 4% of the lean meat component in the emulsion formulation was replaced by 1% treatment ingredient and 3% water.
[b] 2% Treatment = 8% of the lean meat component in the emulsion formulation was replaced by 2% treatment ingredient and 6% water.
[c] Pork lean = Ham *semimembranosous* purchased from Swift and Company (Marshalltown, IA) and trimmed practically free of all visible fat.
[d] Pork fat = Pork backfat purchased from Iowa State University Meat Laboratory (Ames, IA).

Replication 2

Controls

Batch Size = 1500 gm

	Positive Control [a]		Negative Control for 1% [b]		Negative Control for 2% [c]	
Ingredient	**%**	**grams**	**%**	**grams**	**%**	**grams**
Pork Lean [d]	51.98	779.70	47.98	719.70	43.98	659.70
Pork Fat [e]	23.52	352.80	23.52	352.80	23.52	352.80
Ice	11.50	172.50	11.50	172.50	11.50	172.50
Water	11.50	172.50	11.50	172.50	11.50	172.50
Salt	1.50	22.50	1.43	21.45	1.35	20.25
Treatment	0.00	0.00	0.00	0.00	0.00	0.00
Water for Treatment	0.00	0.00	4.07	61.05	8.15	122.25
	100.00%	1500.00	100.00%	1500.00	100.00%	1500.00

[a] Positive control = No lean meat replacement, same control was used for 1% and 2% treatments.
[b] Negative control for 1% = 4% of the lean meat component in the emulsion formulation was replaced by 4% water.
[c] Negative control for 2% = 8% of the lean meat component in the emulsion formulation was replaced by 8% water.
[d] Pork lean = Ham *semimembranosous* purchased from Swift and Company (Marshalltown, IA) and trimmed practically free of all visible fat.
[e] Pork fat = Pork backfat purchased from Iowa State University Meat Laboratory (Ames, IA).

Treatments

Batch Size = 1500 gm

	1% Treatment [a]		2% Treatment [b]	
Ingredient	**%**	**grams**	**%**	**grams**
Pork Lean [c]	47.98	719.70	43.98	659.70
Pork Fat [d]	23.52	352.80	23.52	352.80
Ice	11.50	172.50	11.50	172.50
Water	11.50	172.50	11.50	172.50
Salt	1.43	21.45	1.35	20.25
Treatment	1.00	15.00	2.00	30.00
Water for Treatment	3.07	46.05	6.15	92.25
	100.00%	1500.00	100.00%	1500.00

[a] 1% Treatment = 4% of the lean meat component in the emulsion formulation was replaced by 1% treatment ingredient and 3% water.
[b] 2% Treatment = 8% of the lean meat component in the emulsion formulation was replaced by 2% treatment ingredient and 6% water.
[c] Pork lean = Ham *semimembranosous* purchased from Swift and Company (Marshalltown, IA) and trimmed practically free of all visible fat.
[d] Pork fat = Pork backfat purchased from Iowa State University Meat Laboratory (Ames, IA).

Replication 3

Controls

Batch Size = 1500 gm

	Positive Control [a]		Negative Control for 1% [b]		Negative Control for 2% [c]	
Ingredient	%	grams	%	grams	%	grams
Pork Lean [d]	55.09	826.35	51.09	766.35	47.09	706.35
Pork Fat [e]	20.41	306.15	20.41	306.15	20.41	306.15
Ice	11.50	172.50	11.50	172.50	11.50	172.50
Water	11.50	172.50	11.50	172.50	11.50	172.50
Salt	1.50	22.50	1.43	21.45	1.35	20.25
Treatment	0.00	0.00	0.00	0.00	0.00	0.00
Water for Treatment	0.00	0.00	4.07	61.05	8.15	122.25
	100.00%	1500.00	100.00%	1500.00	100.00%	1500.00

[a] Positive control = No lean meat replacement, same control was used for 1% and 2% treatments.
[b] Negative control for 1% = 4% of the lean meat component in the emulsion formulation was replaced by 4% water.
[c] Negative control for 2% = 8% of the lean meat component in the emulsion formulation was replaced by 8% water.
[d] Pork lean = Ham *semimembranosous* purchased from Swift and Company (Marshalltown, IA) and trimmed practically free of all visible fat.
[e] Pork fat = Pork backfat purchased from Iowa State University Meat Laboratory (Ames, IA).

Treatments

Batch Size = 1500 gm

	1% Treatment [a]		2% Treatment [b]	
Ingredient	**%**	**%**	**%**	**grams**
Pork Lean [c]	51.09	766.35	47.09	706.35
Pork Fat [d]	20.41	306.15	20.41	306.15
Ice	11.50	172.50	11.50	172.50
Water	11.50	172.50	11.50	172.50
Salt	1.43	21.45	1.35	20.25
Treatment	1.00	15.00	2.00	30.00
Water for Treatment	3.07	46.05	6.15	92.25
	100.00%	1500.00	100.00%	1500.00

[a] 1% Treatment = 4% of the lean meat component in the emulsion formulation was replaced by 1% treatment ingredient and 3% water.
[b] 2% Treatment = 8% of the lean meat component in the emulsion formulation was replaced by 2% treatment ingredient and 6% water.
[c] Pork lean = Ham *semimembranosous* purchased from Swift and Company (Marshalltown, IA) and trimmed practically free of all visible fat.
[d] Pork fat = Pork backfat purchased from Iowa State University Meat Laboratory (Ames, IA).

Replication 1

Positive Control [a]

Meat Block (gm) 1132.5

Meat	Composition [b]	Fat	% Fat [c]		% of Meat Needed	Meat Needed (decimal)	Meat Needed (gm)	Meat
Pork Lean [d]	90.4 lean 9.6 fat	9.6		59.6	72.24	0.7224	818.15	**Pork Lean**
			32.5					
Pork Fat [e]	7.9 lean 92.1 fat	92.1		22.9	27.76	0.2776	3314.35	**Pork Fat**
				82.5	100		1132.5	

[a] Control = Fat determination used as a baseline for all formulations.
[b] Composition = Anyl Ray Fat Analyzer (Kartrig Pak, Model 316-48) was used to determine the exact lean and fat content.
[c] % Fat = Formulated for 32.5% fat content in the meat block and targeted fat content of 27.5% fat content in the final product.
[d] Pork lean = Ham *semimembranosous* purchased from Swift and Company (Marshalltown, IA) and trimmed practically free of all visible fat.
[e] Pork fat = Pork backfat purchased from Iowa State University Meat Laboratory (Ames, IA).

Replication 2

Positive Control [a]

Meat Block (gm) 1132.5

Meat	Composition [b]	Fat	% Fat [c]		% of Meat Needed	Meat Needed (decimal)	Meat Needed (gm)	Meat
Pork Lean [d]	90.3 lean 9.7 fat	9.7		60.5	72.63	0.7263	822.75	**Pork Lean**
			32.5					
Pork Fat [e]	7.0 lean 93.0 fat	93.0		22.8	27.37	0.2737	309.90	**Pork Fat**
				83.3	100		1132.5	

[a] Control = Fat determination used as a baseline for all formulations.
[b] Composition = Anyl Ray Fat Analyzer (Kartrig Pak, Model 316-48) was used to determine the exact lean and fat content.
[c] % Fat = Formulated for 32.5% fat content in the meat block and targeted fat content of 27.5% fat content in the final product.
[d] Pork lean = Ham *semimembranosous* purchased from Swift and Company (Marshalltown, IA) and trimmed practically free of all visible fat.
[e] Pork fat = Pork backfat purchased from Iowa State University Meat Laboratory (Ames, IA).

Replication 3

Positive Control [a]

Meat Block (gm) 1132.5

Meat	Composition [b]	Fat	% Fat [c]		% of Meat Needed	Meat Needed (decimal)	Meat Needed (gm)	Meat
Pork Lean [d]	89.7 lean 10.3 fat	10.3		61.0	73.32	0.7332	830.40	**Pork Lean**
			32.5					
Pork Fat [e]	6.5 lean 93.5 fat	93.5		22.2	26.68	0.2668	302.25	**Pork Fat**
				83.2	100		1132.5	

[a] Control = Fat determination used as a baseline for all formulations.
[b] Composition = Anyl Ray Fat Analyzer (Kartrig Pak, Model 316-48) was used to determine the exact lean and fat content.
[c] % Fat = Formulated for 32.5% fat content in the meat block and targeted fat content of 27.5% fat content in the final product.
[d] Pork lean = Ham *semimembranosous* purchased from Swift and Company (Marshalltown, IA) and trimmed practically free of all visible fat.
[e] Pork fat = Pork backfat purchased from Iowa State University Meat Laboratory (Ames, IA).

Replication 1

Controls

Batch Size = 1500 gm

	Positive Control [a]		Negative Control for 1% [b]		Negative Control for 2% [c]	
Ingredient	**%**	**grams**	**%**	**grams**	**%**	**grams**
Pork Lean [d]	54.55	818.15	50.55	758.25	46.55	698.25
Pork Fat [e]	20.96	314.35	20.96	314.35	20.96	314.35
Ice	9.94	149.10	9.94	149.10	9.94	149.10
Water	9.94	149.10	9.94	149.10	9.94	149.10
Spice	2.11	31.65	2.11	31.65	2.11	31.65
Salt	1.82	27.30	1.83	27.45	1.84	27.30
Na Phosphate	0.45	6.75	0.45	6.75	0.45	6.75
Na Erythorbate	0.0413	0.62	0.0391	0.59	0.0369	0.55
Curing Salt (6.25%) [f]	0.1885	2.83	0.1785	2.68	0.1685	2.53
Treatment	0.00	0.00	4.00	60.00	8.00	120.00
Water for Treatment	0.00	0.00	0.00	0.00	0.00	0.00
	100.00%	1500.00	100.00%	1500.00	100.00%	1500.00

[a] Positive control = No lean meat replacement, same control was used for 1% and 2% treatments.
[b] Negative control for 1% = 4% of the lean meat component in the emulsion formulation was replaced by 4% water.
[c] Negative control for 2% = 8% of the lean meat component in the emulsion formulation was replaced by 8% water.
[d] Pork lean = Ham *semimembranosous* purchased from Swift and Company (Marshalltown, IA) and trimmed practically free of all visible fat.
[e] Pork fat = Pork backfat purchased from Iowa State University Meat Laboratory (Ames, IA).
[f] Curing salt (6.25%) = Contains 6.25% sodium nitrite and 93.75% salt.

Treatments

Batch Size = 1500 gm

	1% Treatment [a]		2% Treatment [b]	
Ingredient	**%**	**grams**	**%**	**grams**
Pork Lean [c]	50.55	758.25	46.55	698.25
Pork Fat [d]	20.96	314.35	20.96	314.35
Ice	9.94	149.10	9.94	149.10
Water	9.94	149.10	9.94	149.10
Spice	2.11	31.65	2.11	31.65
Salt	1.83	27.30	1.84	27.60
Na Phosphate	0.45	6.75	0.45	6.75
Na Erythorbate	0.0391	0.59	0.0369	0.55
Curing Salt (6.25%) [e]	0.1785	2.68	0.1685	2.53
Treatment	3.00	45.00	6.00	90.00
Water for Treatment	1.00	15.00	2.00	30.00
	100.00%	1500.00	100.00%	1500.00

[a] 1% Treatment = 4% of the lean meat component in the emulsion formulation was replaced by 1% treatment ingredient and 3% water.

[b] 2% Treatment = 8% of the lean meat component in the emulsion formulation was replaced by 2% treatment ingredient and 6% water.

[c] Pork lean = Ham *semimembranosous* purchased from Swift and Company (Marshalltown, IA) and trimmed practically free of all visible fat.

[d] Pork fat = Pork backfat purchased from Iowa State University Meat Laboratory (Ames, IA).

[e] Curing salt (6.25%) = Contains 6.25% sodium nitrite and 93.75% salt.

Replication 2

Controls

Batch Size = 1500 gm

	Positive Control [a]		Negative Control for 1% [b]		Negative Control for 2% [c]	
Ingredient	%	grams	%	grams	%	grams
Pork Lean [d]	54.85	822.75	50.85	762.75	46.85	702.75
Pork Fat [e]	20.66	309.90	20.66	309.90	20.66	309.90
Ice	9.94	149.10	9.94	149.10	9.94	149.10
Water	9.94	149.10	9.94	149.10	9.94	149.10
Spice	2.11	31.65	2.11	31.65	2.11	31.65
Salt	1.82	27.30	1.83	27.45	1.84	27.30
Na Phosphate	0.45	6.75	0.45	6.75	0.45	6.75
Na Erythorbate	0.0413	0.62	0.0391	0.59	0.0369	0.55
Curing Salt (6.25%) [f]	0.1885	2.83	0.1785	2.68	0.1685	2.53
Treatment	0.00	0.00	4.00	60.00	8.00	120.00
Water for Treatment	0.00	0.00	0.00	0.00	0.00	0.00
	100.00%	1500.00	100.00%	1500.00	100.00%	1500.00

[a] Positive control = No lean meat replacement, same control was used for 1% and 2% treatments.
[b] Negative control for 1% = 4% of the lean meat component in the emulsion formulation was replaced by 4% water.
[c] Negative control for 2% = 8% of the lean meat component in the emulsion formulation was replaced by 8% water.
[d] Pork lean = Ham *semimembranosous* purchased from Swift and Company (Marshalltown, IA) and trimmed practically free of all visible fat.
[e] Pork fat = Pork backfat purchased from Iowa State University Meat Laboratory (Ames, IA).
[f] Curing salt (6.25%) = Contains 6.25% sodium nitrite and 93.75% salt.

Treatments

Batch Size = 1500 gm

	1% Treatment [a]		2% Treatment [b]	
Ingredient	**%**	**grams**	**%**	**grams**
Pork Lean [c]	50.85	762.75	46.85	702.75
Pork Fat [d]	20.66	309.90	20.66	309.90
Ice	9.94	149.10	9.94	149.10
Water	9.94	149.10	9.94	149.10
Spice	2.11	31.65	2.11	31.65
Salt	1.83	27.30	1.84	27.60
Na Phosphate	0.45	6.75	0.45	6.75
Na Erythorbate	0.0391	0.59	0.0369	0.55
Curing Salt (6.25%) [e]	0.1785	2.68	0.1685	2.53
Treatment	3.00	45.00	6.00	90.00
Water for Treatment	1.00	15.00	2.00	30.00
	100.00%	1500.00	100.00%	1500.00

[a] 1% Treatment = 4% of the lean meat component in the emulsion formulation was replaced by 1% treatment ingredient and 3% water.

[b] 2% Treatment = 8% of the lean meat component in the emulsion formulation was replaced by 2% treatment ingredient and 6% water.

[c] Pork lean = Ham *semimembranosous* purchased from Swift and Company (Marshalltown, IA) and trimmed practically free of all visible fat.

[d] Pork fat = Pork backfat purchased from Iowa State University Meat Laboratory (Ames, IA).

[e] Curing salt (6.25%) = Contains 6.25% sodium nitrite and 93.75% salt.

Replication 3

Controls

Batch Size = 1500 gm

	Positive Control [a]		Negative Control for 1% [b]		Negative Control for 2% [c]	
Ingredient	%	grams	%	grams	%	grams
Pork Lean [d]	55.36	830.40	51.36	770.40	47.36	710.40
Pork Fat [e]	20.15	302.25	20.15	302.25	20.15	302.25
Ice	9.94	149.10	9.94	149.10	9.94	149.10
Water	9.94	149.10	9.94	149.10	9.94	149.10
Spice	2.11	31.65	2.11	31.65	2.11	31.65
Salt	1.82	27.30	1.83	27.45	1.84	27.30
Na Phosphate	0.45	6.75	0.45	6.75	0.45	6.75
Na Erythorbate	0.0413	0.62	0.0391	0.59	0.0369	0.55
Curing Salt (6.25%) [f]	0.1885	2.83	0.1785	2.68	0.1685	2.53
Treatment	0.00	0.00	4.00	60.00	8.00	120.00
Water for Treatment	0.00	0.00	0.00	0.00	0.00	0.00
	100.00%	1500.00	100.00%	1500.00	100.00%	1500.00

[a] Positive control = No lean meat replacement, same control was used for 1% and 2% treatments.
[b] Negative control for 1% = 4% of the lean meat component in the emulsion formulation was replaced by 4% water.
[c] Negative control for 2% = 8% of the lean meat component in the emulsion formulation was replaced by 8% water.
[d] Pork lean = Ham *semimembranosous* purchased from Swift and Company (Marshalltown, IA) and trimmed practically free of all visible fat.
[e] Pork fat = Pork backfat purchased from Iowa State University Meat Laboratory (Ames, IA).
[f] Curing salt (6.25%) = Contains 6.25% sodium nitrite and 93.75% salt.

Treatments

Batch Size = 1500 gm

	1% Treatment [a]		2% Treatment [b]	
Ingredient	**%**	**grams**	**%**	**grams**
Pork Lean [c]	51.36	770.40	47.36	710.40
Pork Fat [d]	20.15	302.25	20.15	302.25
Ice	9.94	149.10	9.94	149.10
Water	9.94	149.10	9.94	149.10
Spice	2.11	31.65	2.11	31.65
Salt	1.83	27.30	1.84	27.60
Na Phosphate	0.45	6.75	0.45	6.75
Na Erythorbate	0.0391	0.59	0.0369	0.55
Curing Salt (6.25%) [e]	0.1785	2.68	0.1685	2.53
Treatment	3.00	45.00	6.00	90.00
Water for Treatment	1.00	15.00	2.00	30.00
	100.00%	1500.00	100.00%	1500.00

[a] 1% Treatment = 4% of the lean meat component in the emulsion formulation was replaced by 1% treatment ingredient and 3% water.

[b] 2% Treatment = 8% of the lean meat component in the emulsion formulation was replaced by 2% treatment ingredient and 6% water.

[c] Pork lean = Ham *semimembranosous* purchased from Swift and Company (Marshalltown, IA) and trimmed practically free of all visible fat.

[d] Pork fat = Pork backfat purchased from Iowa State University Meat Laboratory (Ames, IA).

[e] Curing salt (6.25%) = Contains 6.25% sodium nitrite and 93.75% salt.

Replication 1

Positive Control [a]

Meat Block (lbs.) 56.625

Meat	Composition [b]	Fat	% Fat [c]		% of Meat Needed	Meat Needed (decimal)	Meat Needed (lbs.)	Meat
Pork Lean [d]	90.1 lean 9.9 fat	9.9		30.1	57.12	0.5712	32.34	**Pork Lean**
			32.5					
Pork Trim [e]	37.4 lean 62.6 fat	62.6		22.6	42.88	0.4288	24.28	**Pork Trim**
				52.7	100		56.63	

[a] Control = Fat determination used as a baseline for all formulations.
[b] Composition = Anyl Ray Fat Analyzer (Kartrig Pak, Model 316-48) was used to determine the exact lean and fat content.
[c] % Fat = Formulated for 32.5% fat content in the meat block and targeted fat content of 27.5% fat content in the final product.
[d] Pork lean = Pork cushion purchased from Iowa Packing Company (Des Moines, IA).
[e] Pork trim = Pork trim (50/50) purchased from Iowa State University Meat Laboratory (Ames, IA).

Replication 2

Positive Control [a]

Meat Block (lbs.) 56.625

Meat	Composition [b]	Fat	% Fat [c]		% of Meat Needed	Meat Needed (decimal)	Meat Needed (lbs.)	Meat
Pork Lean [d]	89.6 lean 10.4 fat	10.4		22.5	50.45	0.5045	28.57	**Pork Lean**
			32.5					
Pork Trim [e]	45.0 lean 55.0 fat	55.0		22.1	49.55	0.4955	28.06	**Pork Trim**
				44.6	100		56.63	

[a] Control = Fat determination used as a baseline for all formulations.
[b] Composition = Anyl Ray Fat Analyzer (Kartrig Pak, Model 316-48) was used to determine the exact lean and fat content.
[c] % Fat = Formulated for 32.5% fat content in the meat block and targeted fat content of 27.5% fat content in the final product.
[d] Pork lean = Pork cushion purchased from Iowa Packing Company (Des Moines, IA).
[e] Pork trim = Pork trim (50/50) purchased from Iowa State University Meat Laboratory (Ames, IA).

Replication 3

Positive Control [a]

Meat Block (lbs.) 56.625

Meat	Composition [b]	Fat	% Fat [c]		% of Meat Needed	Meat Needed (decimal)	Meat Needed (lbs.)	Meat
Pork Lean [d]	90.1 lean 9.9 fat	9.9		25.2	52.72	0.5272	29.85	**Pork Lean**
			32.5					
Pork Trim [e]	42.3 lean 57.7 fat	57.7		22.6	47.28	0.4728	26.77	**Pork Trim**
				47.8	100		56.63	

[a] Control = Fat determination used as a baseline for all formulations.
[b] Composition = Anyl Ray Fat Analyzer (Kartrig Pak, Model 316-48) was used to determine the exact lean and fat content.
[c] % Fat = Formulated for 32.5% fat content in the meat block and targeted fat content of 27.5% fat content in the final product.
[d] Pork lean = Pork cushion purchased from Iowa Packing Company (Des Moines, IA).
[e] Pork trim = Pork trim (50/50) purchased from Iowa State University Meat Laboratory (Ames, IA).

Replication 1

Batch Size = 75 lbs.

	Control [a]			1% Treatment [b]			2% Treatment [c]		
Ingredient	**%**	**lbs.**	**gms**	**%**	**lbs.**	**gms**	**%**	**lbs.**	**gms**
Pork Lean (88/12) [d]	43.14	32.36		39.14	29.36		35.14	26.36	
Pork Trim (50/50) [e]	32.37	24.28		32.37	24.28		32.37	24.28	
Ice	9.94	7.46		9.94	7.46		9.94	7.46	
Water	9.94	7.46		9.94	7.46		9.94	7.46	
Spice	2.11	1.58		2.11	1.58		2.11	1.58	
Salt	1.82	1.37		1.83	1.37		1.84	1.38	
Na Phosphate	0.45	0.34	153.09	0.45	0.34	153.09	0.45	0.34	153.09
Na Erythorbate	0.0413	0.03	14.05	0.0391	0.03	13.31	0.0369	0.03	12.56
Curing Salt (6.25%) [f]	0.1885	0.14	64.11	0.1785	0.13	60.71	0.1685	0.13	57.32
Treatment	0.00	0.00		1.00	0.75		2.00	1.50	
Water for Treatment	0.00	0.00		3.00	2.25		6.00	4.50	
	100.00%	75.0		100.00%	75.0		100.00%	75.00	

[a] Control = No lean meat replacement, same control was used for 1% and 2% treatments.
[b] 1% Treatment = 4% of the lean meat component in the emulsion formulation was replaced by 1% treatment ingredient and 3% water.
[c] 2% Treatment = 8% of the lean meat component in the emulsion formulation was replaced by 2% treatment ingredient and 6% water.
[d] Pork lean = Pork cushion (88/12) purchased from Iowa Packing Company (Des Moines, IA).
[e] Pork trim = Pork trim (50/50) purchased from Iowa State University Meat Laboratory (Ames, IA).
[f] Curing salt (6.25%) = Contains 6.25% sodium nitrite and 93.75% salt.

Replication 2

Batch Size = 75 lbs.

	Control [a]			1% Treatment [b]			2% Treatment [c]		
Ingredient	**%**	**lbs.**	**gms**	**%**	**lbs.**	**gms**	**%**	**lbs.**	**gms**
Pork Lean (88/12) [d]	38.10	28.58		34.10	25.58		30.10	22.58	
Pork Trim (50/50) [e]	37.40	28.05		37.40	28.05		37.40	28.05	
Ice	9.94	7.46		9.94	7.46		9.94	7.46	
Water	9.94	7.46		9.94	7.46		9.94	7.46	
Spice	2.11	1.58		2.11	1.58		2.11	1.58	
Salt	1.82	1.37		1.83	1.37		1.84	1.38	
Na Phosphate	0.45	0.34	153.09	0.45	0.34	153.09	0.45	0.34	153.09
Na Erythorbate	0.0413	0.03	14.05	0.0391	0.03	13.31	0.0369	0.03	12.56
Curing Salt (6.25%) [f]	0.1885	0.14	64.11	0.1785	0.13	60.71	0.1685	0.13	57.32
Treatment	0.00	0.00		1.00	0.75		2.00	1.50	
Water for Treatment	0.00	0.00		3.00	2.25		6.00	4.50	
	100.00%	75.0		100.00%	75.0		100.00%	75.00	

[a] Control = No lean meat replacement, same control was used for 1% and 2% treatments.
[b] 1% Treatment = 4% of the lean meat component in the emulsion formulation was replaced by 1% treatment ingredient and 3% water.
[c] 2% Treatment = 8% of the lean meat component in the emulsion formulation was replaced by 2% treatment ingredient and 6% water.
[d] Pork lean = Pork cushion (88/12) purchased from Iowa Packing Company (Des Moines, IA).
[e] Pork trim = Pork trim (50/50) purchased from Iowa State University Meat Laboratory (Ames, IA).
[f] Curing salt (6.25%) = Contains 6.25% sodium nitrite and 93.75% salt.

Replication 3

Batch Size = 75 lbs.

	Control [a]			1% Treatment [b]			2% Treatment [c]		
Ingredient	%	lbs.	gms	%	lbs.	gms	%	lbs.	gms
Pork Lean (88/12) [d]	39.80	29.58		35.80	25.58		31.80	22.58	
Pork Trim (50/50) [e]	35.70	26.78		35.70	28.05		35.70	28.05	
Ice	9.94	7.46		9.94	7.46		9.94	7.46	
Water	9.94	7.46		9.94	7.46		9.94	7.46	
Spice	2.11	1.58		2.11	1.58		2.11	1.58	
Salt	1.82	1.37		1.83	1.37		1.84	1.38	
Na Phosphate	0.45	0.34	153.09	0.45	0.34	153.09	0.45	0.34	153.09
Na Erythorbate	0.0413	0.03	14.05	0.0391	0.03	13.31	0.0369	0.03	12.56
Curing Salt (6.25%) [f]	0.1885	0.14	64.11	0.1785	0.13	60.71	0.1685	0.13	57.32
Treatment	0.00	0.00		1.00	0.75		2.00	1.50	
Water for Treatment	0.00	0.00		3.00	2.25		6.00	4.50	
	100.00%	75.0		100.00%	75.0		100.00%	75.00	

[a] Control = No lean meat replacement, same control was used for 1% and 2% treatments.
[b] 1% Treatment = 4% of the lean meat component in the emulsion formulation was replaced by 1% treatment ingredient and 3% water.
[c] 2% Treatment = 8% of the lean meat component in the emulsion formulation was replaced by 2% treatment ingredient and 6% water.
[d] Pork lean = Pork cushion (88/12) purchased from Iowa Packing Company (Des Moines, IA).
[e] Pork trim = Pork trim (50/50) purchased from Iowa State University Meat Laboratory (Ames, IA).
[f] Curing salt (6.25%) = Contains 6.25% sodium nitrite and 93.75% salt.

Appendix 8: Proliant Inc. Protein Ingredient Specification Sheets

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The products used in this project were a variety of ingredients provided by Proliant Inc. The following pages are product information specification sheets on the products that were used in this project.

Treatments:

Spray – Dried Beef Plasma

MyoGel

MyoGel Plus

Chicken Collagen

Turkey Collagen

Whey Protein Concentrate

For more information contact:

Proliant Inc.
2325 North Loop Drive
Ames, Iowa 50010 USA

Phone: 515 / 296-7100
800 / 369-2672

Fax: 515 / 296-7110

Proliant™ B6302 Spray-Dried Beef Plasma

Proliant
The Art of Service
The Science of Protein

Proliant™ B6302
Spray-Dried Beef Plasma
(Formerly AMP 600N)

Proliant B6302 is a highly functional spray-dried meat protein with a low organoleptic profile that exhibits exceptional water binding and emulsification capabilities. It forms an irreversible, strong, elastic gel that greatly improves the texture of many types of processed foods. This 100% natural protein is produced under USDA inspection using a specially designed processing system.

FEATURES / BENEFITS

- Low Organoleptic Profile
- Inhibits Alkaline Proteases
- Forms Strong, Irreversible Elastic Gels
- Excellent Water-Binder and Emulsifier
- Highly Soluble with Low Viscosity
- Improves Texture and Juiciness
- Excellent Amino Acid Profile
- Reduces Costs
- Good Protein Source
- 100% Natural
- Easy To Use

APPLICATIONS

- Surimi
- Seafood Analogs
- Bakery Products
- Pasta
- Hot Dogs
- Chopped and Formed Hams
- Bologna, Mortadella
- Beef Patties, Formed Meat Products
- Vienna Sausages
- Canned / Retorted Products
- Injected Meats

PRODUCT ATTRIBUTES & TYPICAL COMPOSITION

Physical:	Color	Light Beige Powder
	Flavor	Very Mild
Chemical:	Protein	71.1 %
	Fat	3.7 %
	Moisture	7.6 %
Microbiological:	Total Plate Count	20,000 CFU / gram
	Salmonella	Negative / 25 grams

PACKAGING

Heat-sealed, multi-wall Kraft bag with an inner polyethylene liner.

STORAGE / SHELF LIFE

Rotation of stock is recommended. Shelf life is two years from the date of manufacture when stored in a cool, dry environment.

ORDERING INFORMATION: Please refer to product SKU # when ordering.

SKU #	PACKAGING	INGREDIENTS	FOB
10071	55.1 lb (25 kg) bag	Beef Plasma	Fremont, NE
10041	25 kg bag	Plasma bovino em pó, citrato de sódio *(Brazil label)*	Fremont, NE

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Proliant™ P5501 MyoGel™

Proliant
The Art of Service. The Science of Protein.

Proliant™ P5501 MyoGel™
Dehydrated Pork Fatty Tissue

Proliant P5501 is a specially dried meat protein ingredient in granule form that offers excellent functionality and cost savings in processed meat applications. Derived from fresh pork trimmings, it is produced under USDA inspection using stainless steel equipment throughout the process.

■ FEATURES / BENEFITS

- Firm, Heat-Induced Reversible Gelling Characteristics
- Excellent Water-Binding Capability
- Good Emulsification Ability
- Improves Texture and Juiciness
- Decreases Formulation Costs
- High Heat / Pressure Stability
- Contributes Pork Meat Flavor
- Easy To Use
- Shelf Stable

■ APPLICATIONS

- Hot Dogs
- Course Ground Sausages
- Fermented Sausages
- Chopped and Formed Ham
- Bologna
- Mortadella
- Pork Patties
- Vienna Sausages
- Other Processed Meat Products

■ PRODUCT ATTRIBUTES & TYPICAL COMPOSITION

Physical:	Color	Tan Granule
	Flavor	Mild Flavor
Chemical:	Protein	68.1 %
	Fat	30.1 %
	Moisture	2.3 %
Microbiological:	Total Plate Count	15,000 CFU / gram
	Salmonella	Negative / 25 grams

■ PACKAGING

Polyethylene / nylon bag filled by a modified atmosphere process. The bag is vacuum packed and then nitrogen flushed to result in an airtight yet malleable package. The bag is meticulously constructed to prevent moisture and oxygen penetration, and is further enclosed in a corrugated box.

■ STORAGE / SHELF LIFE

Rotation of stock is recommended. Shelf life is two years from the date of manufacture when stored in a cool, dry environment.

■ ORDERING INFORMATION: Please refer to product SKU # when ordering.

SKU #	PACKAGING	INGREDIENTS	FOB
4501 4502 *(Canada)* 4504 *(Mexico)*	55.1 lb (25 kg) box	Dehydrated Pork Fatty Tissue, Tocopherol, Natural Flavor and Citric Acid added to help protect flavor	Harlan, IA
45102 *(Taiwan)*	55.1 lb (25 kg) box	Dehydrated Pork Fatty Tissue, contains less than 0.15% Tocopherol, Natural Flavor and Citric Acid added to help protect flavor	Harlan, IA

REM 6/11/01 v.6

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Proliant™ P5501 MyoGel™ Plus

Proliant
The Art of Service
The Science of Protein

Proliant™ P5601 MyoGel™ Plus
Pork Collagen

Proliant P5601 MyoGel Plus is a specially dried meat protein ingredient in powder form, which physically and analytically replaces a portion of the lean meat in processed meat products. MyoGel Plus offers excellent functionality and cost savings in processed meat applications. Derived from fresh pork trimmings, it is produced under USDA inspection using stainless steel equipment throughout the process.

■ FEATURES / BENEFITS

- Replaces Lean Meat
- Firm, Heat-Induced Reversible Gelling Characteristics
- Excellent Water-Binding Capability
- Good Emulsification Ability
- Maintains Product Texture – Even in Highly Extended Products
- Improves Texture and Juiciness
- Decreases Formulation Costs
- High Heat / Pressure Stability
- Easy To Use / Shelf Stable

■ APPLICATIONS

- Hot Dogs
- Course Ground Sausages
- Fermented Sausages
- Chopped and Formed Ham
- Bologna
- Mortadella
- Meat Patties
- Vienna Sausages
- Other Processed Meat Products

■ PRODUCT ATTRIBUTES & TYPICAL COMPOSITION

Physical:	Color	Light Tan Powder
	Flavor	Mild Flavor
Chemical:	Protein	88.3 %
	Fat	12.3 %
	Moisture	1.3 %
Microbiological:	Total Plate Count	15,000 CFU / gram
	Salmonella	Negative / 25 grams

■ PACKAGING

Polyethylene / nylon bag filled by a modified atmosphere process. The bag is vacuum packed and then nitrogen flushed to result in an airtight yet malleable package. The bag is meticulously constructed to prevent moisture and oxygen penetration, and is further enclosed in a corrugated box.

■ STORAGE / SHELF LIFE

Rotation of stock is recommended. Shelf life is two years from the date of manufacture when stored in a cool, dry environment.

■ ORDERING INFORMATION: Please refer to product SKU # when ordering.

SKU #	PACKAGING	INGREDIENTS	FOB
45070 45590 (Canada)	55.1 lb (25 kg) box	Pork Collagen, Tocopherol, Natural Flavor and Citric Acid added to help protect flavor	Harlan, IA

REM 6/11/01 v.4

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Proliant™ C5501 Chicken Flavor

Proliant
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Proliant™ C5501 Chicken Flavor
From Chicken Skins

Proliant C5501 Chicken Flavor offers excellent functionality, mild chicken flavor, and cost savings in processed meat applications. A special feature is the product's favorable labeling, which is required by USDA to read "chicken flavor (from chicken skins)". It is produced under USDA inspection using stainless steel equipment throughout the process.

■ FEATURES / BENEFITS

- Thermal, reversible gel
- Excellent Water-Binding Capability
- Good Emulsion Stabilizer
- Improves Texture and Juiciness
- Decreases Formulation Costs
- High Heat / Pressure Stability
- No off-flavor or bitter characteristics
- Easy-To-Use Powder

■ APPLICATIONS

- Processed Meat Emulsions
- Coarse Ground Sausages
- Fermented Sausages
- Chopped and Formed Hams
- Battered / Breaded Poultry
- Poultry Marinades
- Chicken Nuggets
- Chicken Patties

■ PRODUCT ATTRIBUTES & TYPICAL COMPOSITION

Physical:	Color	Light Tan Powder
	Flavor	Mild Chicken Flavor
Chemical:	Protein	70.0 %
	Fat	28.0 %
	Moisture	1.5 %
Microbiological:	Total Plate Count	15,000 CFU / gram
	Salmonella	Negative / 25 grams

■ PACKAGING

A polyethylene / nylon bag is vacuum packed and then nitrogen flushed to result in an airtight yet malleable package. The bag is meticulously constructed to prevent moisture and oxygen penetration, and is further enclosed in a corrugated box.

■ STORAGE / SHELF LIFE

Rotation of stock is recommended. Shelf life is two years from the date of manufacture when stored in a cool, dry environment. Refrigerate after opening.

■ ORDERING INFORMATION: Please refer to product SKU # when ordering.

SKU #	PACKAGING	INGREDIENTS	FOB
12726	55.1 lb (25 kg) box	Chicken Flavor (from chicken skins), Tocopherol, Natural Flavor and Citric Acid added to help protect flavor	Harlan, IA

REM 4/1/01 v.2

2325 North Loop Drive • Ames, Iowa 50010 • (515) 296-7100 • (800) 369-2672 • Fax (515) 296-7110 • www.proliantinc.com • Products of USA

Proliant™ T5501 Turkey Flavor

Proliant
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The Science of Protein

Proliant™ T5501 Turkey Flavor
From Turkey Skins

Proliant T5501 Turkey Flavor offers excellent functionality, mild turkey flavor, and cost savings in processed meat applications. A special feature is the product's favorable labeling, which is required by USDA to read "turkey flavor (from turkey skins)". It is produced under USDA inspection using stainless steel equipment throughout the process.

■ FEATURES / BENEFITS

- Thermal, reversible gel
- Excellent Water-Binding Capability
- Good Emulsion Stabilizer
- Improves Texture and Juiciness
- Decreases Formulation Costs
- High Heat / Pressure Stability
- No off-flavor or bitter characteristics
- Easy-To-Use Powder

■ APPLICATIONS

- Processed Meat Emulsions
- Coarse Ground Sausages
- Fermented Sausages
- Chopped and Formed Hams
- Battered / Breaded Poultry
- Poultry Marinades
- Turkey Nuggets
- Turkey Patties

■ PRODUCT ATTRIBUTES & TYPICAL COMPOSITION

Physical:	Color	Light Tan Powder
	Flavor	Mild Turkey Flavor
Chemical:	Protein	77.3 %
	Fat	20.1 %
	Moisture	2.0 %
Microbiological:	Total Plate Count	15,000 CFU / gram
	Salmonella	Negative / 25 grams

■ PACKAGING

A polyethylene / nylon bag is vacuum packed and then nitrogen flushed to result in an airtight yet malleable package. The bag is meticulously constructed to prevent moisture and oxygen penetration, and is further enclosed in a corrugated box.

■ STORAGE / SHELF LIFE

Rotation of stock is recommended. Shelf life is two years from the date of manufacture when stored in a cool, dry environment. Refrigerate after opening.

■ ORDERING INFORMATION: Please refer to product SKU # when ordering.

SKU #	PACKAGING	INGREDIENTS	FOB
12306	55.1 lb (25 kg) box	Turkey Flavor (from turkey skins), Tocopherol, Natural Flavor and Citric Acid added to help protect flavor	Harlan, IA

USDA regulations and policies limit the use of additives in many types of meat products, particularly those with standards of identities. Please refer to the appropriate policies regarding usage and labeling.

REM 4/1/02 v.2

2325 North Loop Drive • Ames, Iowa 50010 • (515) 296-7100 • (800) 369-2672 • Fax (515) 296-7110 • www.proliantinc.com • Products of USA

Proliant™ 8600 Whey Protein Concentrate

Proliant
The Art of Service. The Science of Protein.

Proliant™ 8600 Water-Binding / Gelling
Partially Hydrolyzed Whey Protein Concentrate 80%
(Formerly AMP 80)

Proliant 8600 is a spray-dried whey protein with the functional attributes essential for meat applications. It is derived from fresh, sweet dairy whey that is further processed by a special ultrafiltration procedure, which concentrates the protein to an 80 percent level.

FEATURES / BENEFITS
- Firm, Heat-induced Gelling Characteristics
- Superior Protein Source
- Low Viscosity in Brine
- High Solubility
- Outstanding Emulsification Ability
- Excellent Water-Binding
- Kosher Ⓤ and Halal Approved
- GMO Free

APPLICATIONS
- Emulsion Meat Products
- Low-Fat Products
- Surimi
- Ground Restructured Products
- Whole Muscle Meats
- Formed Meat Products
- Nutrition

PRODUCT ATTRIBUTES & TYPICAL COMPOSITION

Physical:	Color	Cream Powder
	Flavor	Mild Flavor
Chemical:	Protein	81.6 %
	Fat	4.5 %
	Moisture	4.3 %
Microbiological:	Total Plate Count	10,000 CFU / gram
	Salmonella	Negative / 25 grams

PACKAGING
Heat-sealed, multi-wall Kraft bag with an inner polyethylene liner.

STORAGE / SHELF LIFE
Rotation of stock is recommended. Shelf life is two years from the date of manufacture when stored in a cool, dry environment.

ORDERING INFORMATION: Please refer to product SKU # when ordering.

SKU #	PACKAGING	INGREDIENTS	FOB
2802	44.09 lb (20 kg) bag	Partially Hydrolyzed Whey Protein Concentrate	Hilmar, CA

REM 4/22/02 v. 4

2325 North Loop Drive • Ames, Iowa 50010 • (515) 296-2100 • (800) 369-3672 • Fax (515) 296-2110 • www.proliantinc.com • Products of USA

Appendix 9: Red Arrow Products Company LLC Liquid Smoke Specification Sheet

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The liquid smoke product used in this project was provided by Red Arrow Products Company LLC. The liquid smoke used was *Charsol Select 24P*. The drench cabinet was filled with 80% cold water and 20% liquid smoke. The frankfurters were drenched for 90 seconds. The following pages are product information specification sheets on the product that was used in this project.

For more information contact:

Red Arrow Products Company LLC
633 South 20th Street
Manitowoc, WI USA 54220-1537

Phone: 920 / 683-5500

Fax: 920 / 683-5524

RED ARROW

SPECIFICATIONS

CHARSOL® SELECT 24P

THE PRODUCT

Aqueous solution of natural smoke flavors produced by controlled pyrolysis of mixed hardwoods with additional processing to more closely match the flavor of traditional vaporous smoke.

CHEMICAL PROPERTIES

pH	2.5-3.5
Total Acidity (as acetic)	7.0-9.0 %
Smoke Flavor Compounds	15.0-20.0 mg/ml
Carbonyls	22.0-30.0 %
Density (ave.)	9.5 lb./gal.

PHYSICAL PROPERTIES

Clear, brown liquid with mild hardwood smoke aroma.

SUGGESTED USES

To impart a smoke color and flavor to processed meat by direct addition or drenching. Recommended usage levels are 2-4 oz./100 lbs. of product.

APPROVALS

Considered GRAS by the FDA and USDA when used in accordance with good manufacturing practice. Certified Kosher for Passover - LEOCHLEI KITNIYOT. Certified Halal. Approved for use by Agriculture Canada

STORAGE

Recommended shelf life is two years when stored under cool conditions, 45-75°F. Freezing does not harm this product.

PACKAGING (Item Codes)

Available in 5 (R24P-005), 30 (R24P-030) and 55 (R24P-055) gallon units.

MISCELLANEOUS

Designed for external application to meat products to provide a high color and a very mild smoke flavor. Contains Polysorbate 80 to solubilize smoke flavor compounds and inhibit precipitation.

Red Arrow Products Company LLC • 633 South 20th Street • Manitowoc, WI 54220-1537
MAILING ADDRESS: P.O. Box 1537 • Manitowoc, WI 54221-1537 • TEL: 920-683-5500 • FAX: 920-683-5524

CHARSOL® SELECT 24P

LABELING

USDA: In accordance with Policy Memo 058-A.

FDA: Natural smoke flavor, or smoke flavoring, or included in "other flavors", in ingredients listing.

NUTRITIONAL DATA (By Calculation)

Quantity: 100g

Ash (g)	<0.1
Calories	251
Calories from fat	39
Carbohydrates (g)	<2
Cholesterol (g)	0
Protein (g)	0
Dietary Fiber (g)	0
Moisture (g)	50
Fat Total (g)	4
Fat Saturated (g)	<1
Fat Polyunsaturated (g)	0
Vitamin A Total (RE)	0
Thiamine B1 (mg)	0
Riboflavin B2 (mg)	0
Niacin B3 (mg)	0
Cobalamin B12 (mcg)	0
Vitamin C (mg)	0
Vitamin E (mg)	0
Calcium (mg)	6.8
Chloride (mg)	2.3
Copper (mg)	<0.1
Iron (mg)	<0.1
Magnesium (mg)	2.2
Phosphorus (mg)	<0.1
Potassium (mg)	2.1
Selenium (mg)	<0.1
Sodium (mg)	3.1
Zinc (mg)	<0.1

14 October, 2002

*Smoke derived organics are not classified as fat, protein or carbohydrates, but have caloric value of 3.5 calories/g.

Appendix 10: Thermal Emulsion Stability (Rongey Method)

Rongey EH. 1965. A simple objective test for sausage emulsion quality. Proc of Meat Ind. Res. Conf. American Meat Institute Foundation, Chicago, IL.

Sebranek JG, Lonergan SM, King-Brink M, Larson E. 2001. Emulsion evaluations and water holding capacity. In: Meat Science and Processing - 3rd edition. Zenda, WI: Peerage Press. pp 134-146.

Rongey Method

1. Place a glass disc into a Wierbicki tube. Label the Wierbicki tubes.
   - record the tube identification
   - record the weight

2. Fill the Wierbicki tube with approximately 25 grams of emulsion by resting the stuffing horn on the glass disc and simultaneously turning the stuffer handle. Keep some pressure on the emulsion so that it fills the tube without air pockets, but be careful not to force the emulsion past the glass disc.

3. Reweigh the filled Wierbicki tube to get the actual sample weight.
   - record the weight

4. Cook the samples in a 72 °C/162 °F water bath for 30 minutes.

5. Remove and allow to cool for 2-3 minutes.

6. Centrifuge at low speed (10,000 rpm) for 5 minutes.

7. Remove the Wierbicki tubes from the centrifuge machine and read the amounts of separated fat (top layer) and separated water (bottom layer).
   - record the volumes

8. Determine % water separation and % fat separation.

   Percent water separation = (ml water / sample weight) x 100

   Percent fat separation = (ml fat / sample weight) x 100

   Percent total liquid separation = % water separation + % fat separation

9. For each treatment measurements were made in duplicate.

Appendix 11: TA.XT2i Puncture Analysis

Puncture Test

1. The puncture test was selected because the results from the samples could be directly compared even though the samples may have slightly different diameters.

2. Three samples were analyzed (not in each phase of the research):
   - centrifuge tube
   - frankfurter skin-on
   - frankfurter skin-off

3. The penetration test calculates:
   - the peak force to penetrate into the sample for exterior firmness
   - the mean force between 6.0 mm and 10.0 mm of penetration for interior firmness

4. A 3 mm diameter stainless steel puncture probe (TA-52) was used.

5. The 3 mm probe was programmed to penetrate 12 mm into each sample after the TA.XT2i detects the sample's surface at 12 grams of resistance.

6. The penetration was 1.5 mm/second.

7. The pre-test speed was 3.0 mm/second and the post-test speed was 10.0 mm/second.

8. Samples were tested at room temperature (one hour after being removed from refrigeration).

9. No tests were conducted within the last ½" of the end of the sample.

10. Three readings were taken per sample and the experiment was conducted in duplicate.

Macro for Skin-on Samples

1.	Clear Graph Results	
2.	Redraw	
3.	Search Forwards	
4.	Go to Min. Time	
5.	% of Max. +ve Distance	100.0%
6.	Drop Anchor	1
7.	Mark Force	
8.	% of Max. +ve Distance	100.0%
9.	Drop Anchor	2
10.	Mean	

Macro for Skin-off Samples

1.	Clear Graph Results	
2.	Redraw	
3.	Search Forwards	
4.	Go to Min. Time	
5.	Go to Time	2.000 s
6.	Drop Anchor	1
7.	Go to Time	4.000 s
8.	Drop Anchor	2
9.	Max. Force in Anchors	100.0%
10.	Drop Anchor	3
11.	Mark Force	
12.	% of Max. +ve Distance	100.0%
13.	Drop Anchor	4
14.	Mean	

Appendix 12: TA.XT2i Texture Profile Analysis

Two Compression Test

1. Texture analysis was performed using a TA.TX2 Texture Analyzer.

2. Sample size was cut to yield a one inch (2.54 cm) cylinder.

3. Four samples were analyzed (not in each phase of the research):
   - Centrifuge tube
   - Centrifuge core
   - Frankfurter skin-on
   - Frankfurter skin-off

4. Measurements were taken for hardness 1 (first bite), cohesiveness, chewiness, and springiness.

5. Texture attributes were divided by the compression quantity:
   50% compression
   - cohesiveness and chewiness

   72% compression
   - hardness 1, hardness 2, and springiness

6. Texture expert software was used and the TA.TX2 Texture Analyzer was calibrated with a 5 kg weight.

7. The pre-test speed was set at 2.0 mm per second and the post-test speed was set at 5.0 mm per second.

8. The tests were performed at 3.3 mm per second with a 3 second delay between compressions at:
   - 18.0 mm compression (72%)
   - 12.7 mm compression (50%)

9. A 5 gm change in force was required to signal that the sample was present.

10. A TA-4 (40 mm cylinder) was used and the computer acquired 200 points per second during the experiment.

11. One reading was taken per sample and the experiment was conducted in triplicate.

Macro for the Samples

1.	Clear Graph Results	
2.	Go to Max. Time	
3.	Set Force Threshold	50.0 g
4.	Search Backwards	
5.	Go to Min. Time	
6.	Search Forwards	
7.	Drop Anchor	1
8.	% of Max. +ve Force	100.0%
9.	Mark Force	
10.	Drop Anchor	2
11.	Go to Last Force	
12.	Select Anchor	1
13.	Select Anchor	2
14.	Area	
15.	Go to Force	0.0g
16.	Drop Anchor	3
17.	Peak Distance +	
18.	Search Backwards	
19.	Go to Last Force	
20.	Drop Anchor	4
21.	Search Forwards	
22.	Peak Distance	
23.	Drop Anchor	5
24.	Go to Last Force	
25.	Search Backwards	
26.	Peak Force +	
27.	Mark Force	
28.	Select Anchor	4
29.	Select Anchor	5
30.	Travel	
31.	Area	

Appendix 13: pH Measurement

1. The pH was measured on the raw emulsion and cooked samples of each treatment.

2. Samples were measured using a pH-STAR Pistol (SFK Technology).

3. Before the measurement took place, the pH-STAR Pistol was calibrated using the technical calibration solutions of pH 4.6 and pH 7.

4. The calibration solutions were refrigerated because the pH was taken on refrigerated samples (2 °C).

5. The tip of the electrode was inserted in the sample.
   - record the tube identification number
   - record the pH value

6. The tip of the electrode was rinsed with distilled water between sample readings.

7. For each treatment, measurements were made in duplicate.

8. The pH of the samples were averaged by converting the recorded pH into an inverse log number, averaging the inverse log of the two recorded samples, and then converting the inverse log back to the pH value.

Appendix 14: Proximate Analysis

[A.O.A.C.] Association of Official Analytical Chemists. 1990a. Fat (crude) or ether extract in meat (AOAC 960.39). In: Official Methods of Analysis, 15th ed. Arlington, VA. 2:931-948.

[A.O.A.C.] Association of Official Analytical Chemists. 1990b. Moisture in meat (AOAC 950.46). In: Official Methods of Analysis, 15th ed. Arlington, VA. 2:931-948.

[A.O.A.C.] Association of Official Analytical Chemists. 1993. Crude protein in meat and meat products (AOAC 992.15). In: Official Methods of Analysis, 15th ed. 4th suppl. Arlington, VA. P 197-198.

Sample Preparation (Modified)

1. Section meat samples into very small (<1 cm squares) pieces.
2. Grind (chop) the sample into mixed substance using a food processor.
3. Grind 2 to 3 minutes until the sample has been ground into a mixed substance, transfer the sample to a labeled plastic bag and secure by tying a knot.
4. Store the sample in refrigerated conditions 0 °C (32 °F) until analysis.

Moisture Analysis

1. Label the thimbles with a pencil (not pen) before drying. Thimbles should be handled with tongs or while wearing gloves. Work rapidly so thimbles won't collect excess moisture. For fatty (approximately > 20% fat) samples, place a ball of cotton in the bottom of the thimble before drying.
2. Check that the analytical balance is clean and level.
3. After zeroing, record the number of the thimble, weigh, and record the weight of the thimble. Zero the scale again.
4. Weigh approximately 5.0 grams of sample into the thimble (place it in small pieces, not one large piece) with a spatula. Record the weight of the sample. For fatty samples, use approximately 4.0 grams.
5. Place the samples into the gravity oven for 18 hours at 100-102 °C.
6. Transfer the sample directly to a desiccator and allow to cool for 30 minutes.

7. Weigh and record the dried weight of the samples. Determine the percent moisture content as follows:

   Moisture (%) = [(wet sample wt. – dried sample wt.) / wet sample wt.] x 100

8. For each treatment measurements were made in duplicate.

Fat Analysis Using Ether Extraction

1. Take samples from moisture analysis and place into the Soxhlet fat extraction tubes. Make sure that all the samples are below the level where the ether drains off (curved glass on outside of tube).

2. Add 200ml (if using small 500 ml flask) of petroleum diethyl ether to clean boiling flasks until about ¾ full. Add 2 to 3 glass beads as a boiling aid.

3. Connect the extraction flask to the boiling flask and Soxhlet apparatus. Place lubriseal on the joint. Mount both to the condensing units on top of extraction flasks using lubriseal around joint.

4. Turn on condensing water so it runs at a steady stream.

5. Set Rheostats on high and run for 6 hours.

6. Place ether soaked samples onto a rack in a fume hood for at least 10-15 minutes to allow any remaining ether to dissipate.

7. Place samples in drying oven for 4 hours to remove any possible moisture then place in dessicator for 1/2 hour to cool.

8. Weigh and record the weight of the samples. Calculate fat on wet basis with the following equation:

   Fat (%) = [(dried sample wt. - extracted sample wt.) / wet sample wt.] x 100

9. For each treatment measurements were made in duplicate.

Protein Analysis

1. Protein was analyzed by using a nitrogen analyzer (Model FP 428, LECO Corp., St. Joseph, MI).

2. A combustion method was used to determine the nitrogen released at high temperature and measured by thermal conductivity.
3. A nitrogen-to-protein conversion factor of 6.25 was used.

4. Weigh out approximately 250-350 mg of meat sample into the tared piece of foil. The sample ID is entered into the machine and the weight is recorded.

5. Protein analysis is conducted using a Leco Protein Analyzer. The Leco Protein Analyzer is run according to the manufacturer's directions.

6. For each treatment, measurements were made in duplicate.

Appendix 15: Color Analysis

Internal color analysis was performed using a Hunter Labscan instrument (Model LS, 1500).

Calibration

1. A port size of 1.27 cm was used with the A illuminant as a light source.

2. A 10° standard observer was used.

3. Calibrate the Hunterlab Labscan by covering the calibration plates with Saran film.

Color Measurement

1. Two samples were analyzed:
   - Centrifuge tube
   - Frankfurter skin-on

2. The Hunterlab Labscan measures CIE L*, a*, and b*
   - L* (lightness)
     100 = Perfect whiteness
     50 = Gray
     0 = Black
   - a* (redness/greenness)
     a - = Greenness
     a 0 = Gray
     a += Redness
   - b* (yellowness/blueness)
     b - = Blueness
     b 0 = Gray
     b += Yellowness

4. Samples were sliced in half longitudinally.

5. Samples were covered with Saran film and readings were taken.

5. Three readings were taken per sample (i.e. tube or frankfurter) and two samples were measured, giving a total of six measurements per treatment.

Appendix 16: Purge Analysis

1. Purge loss values were collected for five weeks starting one day after packaging:
   - Day 1
   - Day 7
   - Day 14
   - Day 21
   - Day 28

2. Two packages were analyzed per treatment:
   - Six frankfurters / package

3. Packages (containing the frankfurters) were weighed.

4. Packages were opened, drained, and the packaging material was blotted dry.

5. The frankfurters and packaging material were then reweighed to determine the weekly purge loss.

6. Purge loss was calculated by the following equation:

Percent = 100 - ((frankfurter weight + dried package weight) / initial package weight) x 100
purge loss

Appendix 17: Iowa State University Institutional Review Board for Human Subjects

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IOWA STATE UNIVERSITY

Human Subjects Review Form & Instructions

The Instructions are pages 1 & 2 of this document and the Form are pages 3-5. Please refer to these instructions as you complete the form.

At Iowa State University, the Institutional Review Board (IRB) reviews all research involving human subjects, including proposals to gather data from subjects for theses, dissertations, and other student projects. The committee has representatives from various areas within the university and includes a member from the community. Present members are R. Sharp (Chair for the Committee, Health and Human Performance); M. L. Damhorst (Textiles and Clothing); E. Hemann (Community Member); P. Kain (Physician); N. Ladjahasan (Institute for Design Research & Outreach); F. Lorenz (Sociology); N. Scott (Psychology); M. Shulman (Physician); D. Winsor (English); Alternates: V. Ryan (Sociology); S. Sheldahl (Physician).

Proposals are reviewed weekly. **Forms submitted to Janell Meldrem (IRB administrator, 2810 Beardshear Hall) before 9:00 a.m. Tuesday will be reviewed on Thursday of that week.** Those submitted after that will be held until the following week. The **signed** original and accompanying materials and **two** copies of the form and accompanying materials are to be submitted for each research project involving human subjects which is conducted by persons associated with Iowa State University. Missing information may delay the review. Questions should be addressed to Janell Meldrem (meldrem@iastate.edu, 294-4566) or Rick Sharp (rlsharp@iastate.edu, 294-8650). All forms, policies and training information are at this address: http://grants-svr.admin.iastate.edu/VPR/humansubjects.html.

Explanation of specific items on the form: **Please type all information on the form.**

1. State the title of your research project.

2. Provide the appropriate information and a signature. It is the responsibility of the principal investigator to bring additions to or changes in procedures involving subjects to the attention of the committee after the project has been approved. If the principal investigator is a student, the research advisor or classroom instructor must sign.

3. Space is provided for the signatures of co-investigators, major professors of graduate students, advisors, or others responsible for the research. **A professor must sign for student research.**

4. **NEW:** This policy will go into effect 8/30/02. All PI's, Co-PI's and key personnel must have taken one of the offered human subjects assurance training before a project will be reviewed.

5. Check appropriate box.

6. Check all that apply. If a project will have minors (under 18), a signature line for their assent and a signature line for parental consent must be listed on the informed consent document.

7. Check whether the proposal has been, will be, or will not be routed to the Office of Sponsored Programs Administration for signatures. Identify the source of support for the project, i.e., external, internal, department, self. If external or internal, list source/sponsor. **Include one copy of the complete proposal if you are or have submitted to a Federal agency.** If the grant title differs from the human subjects title, please list it.

8. Briefly describe your project. **Include one copy of the complete proposal if you are or have submitted to a Federal agency.** Include brief statements describing **(A)** the problem to be examined, the methods to be used in gathering data, and the nature of the data to be gathered as well as **(B)** the method for selecting subjects and their characteristics (age, location, sex). This should include a description of how subjects will be involved. **Data-gathering survey instruments must be attached as an addendum**; if they have not been completed, examples of the types of questions to be asked must be listed and the instrument submitted after it has been completed. Also, clearly indicate the nature of the processes involved if any incentives, compensations, and/or follow-up techniques will be used in efforts to obtain data from subjects.

9. Informed consent means the knowing consent of an individual or her/his legally authorized representative, so situated as to be able to exercise free power of choice without undue inducement or any element of force, fraud, deceit, duress, or other form of constraint or coercion. The required basic elements of information necessary to such consent include: **(1)** an explanation of the procedures to be followed and their purposes, including identification of any procedures that are experimental; **(2)** a description of any reasonably foreseeable discomforts or risks; **(3)** a description of any benefits reasonably to be expected; **(4)** a disclosure of any appropriate alternative procedures that might be advantageous for the subject; **(5)** an offer to answer any inquiries concerning the procedures, provide the PI's contact information and for a student project, the major professor or supervising faculty member's contact information must also be listed; and **(6)** an instruction that the person is free to withdraw her/his consent and to discontinue participation in the project or the activity at any time without prejudice to the subject (45 CFR 46.116). In addition, **(7)** subjects must be informed of efforts to keep confidential any data they provide. **(8)** Specify the amount of time required from the subject. **Signed informed consent** means the subject or her/his legally authorized representative will sign a form consenting to act as a subject. Minors between the ages of 8-17 must be given the opportunity to assent to participation in research. Documents should be written in language that is

easily understandable. Assent by minors does not replace the requirement of parental/guardian consent. **Modified informed consent** refers to those situations where signatures are not obtained; this can be considered in those instances when risk is minimal, signed consent would invalidate objectives of considerable and immediate importance, or any reasonable alternative means for attaining these objectives would be less advantageous to the subjects. For some surveys involving interviews or mailed questionnaires, modified informed consent may be implied by the subject's completion of the survey instrument. In such cases, a cover letter or an outline of information to be verbally conveyed to subjects must be submitted. **(No matter what type of consent is used, an information sheet covering the eight points listed must be submitted.)** So that subjects truly can provide informed consent, this information will be read by or to the subject and/or parent and/or legally authorized representative. If signed informed consent will be obtained, include a copy of the form to be used for this purpose.

NEW: The informed consent document should not be placed on letterhead and should have a one-inch top margin to allow for an IRB approval & expiration date stamp. This stamp will help assure that the current IRB approved document is being used and as a reminder to when IRB approval expires. Go to the Human Subjects Research Office web site for the Informed Consent Document that should be used. http://grants-svr.admin.iastate.edu/VPR/humansubjects.html.

10. If personal identifiers (e.g. names, code numbers) are used, discuss how confidentiality of data will be maintained (who will have access to the data, where will it be kept, etc.) All staff and students who assist principal investigators and who handle data must be informed about the need to insure confidentiality and agree to maintain confidentiality.

11. Identify procedures that may involve risk or discomfort. Explain alternative procedures that may be used, if any; note the legal and/or ethical concerns involved, list safety precautions being taken, and provide justification for procedures involving risk or discomfort. A subject at risk is defined as any individual who may be exposed to the possibility of injury, including physical, psychological, or social injury, as a consequence of participation in any research, development, or related activity which departs from the application of those established and accepted methods necessary to meet her/his needs or which increases the ordinary risks of daily life, including the recognized risks inherent in a chosen occupation or field of service.

12-16. Self-explanatory.

17. List the date of when first contact will be made with the subjects, whether directly or indirectly. If secondary data is being used, indicate the date access to the information will be made or given to the PI. Submission of forms should be submitted at least two weeks before the anticipated start date to allow for revisions or for a full committee review.

18. Indicate the date on which it is anticipated that audio or visual tapes will be erased, if applicable. Or note the approximate date when identifiers will be removed from

completed survey instruments, if applicable; provide justification if identifying information will be retained on the instruments and indicate measures to be used to protect the confidentiality of information provided by the subjects.

19. **The head or chair of the department or administrative unit to which the principal investigator is affiliated must sign this form.** If the PI or Co-Pi is also the DEO, a Dean signature authority must sign. This indicates that the head or chair has been notified that a research project using human subjects has been proposed and that provisions for the use of subjects set by the department, administrative unit, and/or profession have been satisfied.

20. The initial decision of the committee will be noted. If the project is approved with no further action, the chair will sign. A photocopy will be returned to the principal investigator, as well as to the departmental executive officer. The original will be filed with the Human Subjects Research Office.

21. If follow-up action is required, the decision on the resubmission will be noted and signed by the chairperson. A photocopy will be returned to the principal investigator, as well as to the departmental executive officer. The original will be filed in the Human Subjects Research Office.

OFFICE USE ONLY
Key Personnel Training: ☐ Completed IRB Review Date: _____ Project ID# _____
☐ Incomplete*IRB Approval Date: _____ Oracle ID# _____
*If incomplete, date completed: _____ IRB Expiration Date: _____

Iowa State University Human Subjects Review Form

(Please type this form & submit the original & two copies with three copies of all attachments)

1. Title of Project: Sensory Assessment of the Textural Characteristics of Frankfurters

2. I agree to provide the proper surveillance of this project to insure that the rights and welfare of the human subjects are protected. I will report any adverse reactions to the committee. Additions to or changes in research procedures after the project has been approved will be submitted to the committee for review. I agree that all key personnel involved in conducting human subjects research will receive training in the protection of human subjects. This also includes all PI's and Co-PI's. Access to the 45 CFR 46, Belmont Report, and ISU's Federal Wide Assurance is available to all PI's via the WWW. http://grants-svr.admin.iastate.edu/VPR/humansubjects.html. I agree to request renewal of approval for any project continuing more than one year.

Jane A. Love — Typed name of principal investigator
11/18/02 — Date
_____ — Signature of principal investigator

Food Science and Human Nutrition — Department
1117 Human Nutritional Sciences Building — Mailing Address for Correspondence

515-294-4361 jlove@iastate.edu
Phone number **and** email

2a. Principal investigator
☒ Faculty ☐ Staff ☐ Postdoctoral ☐ Graduate Student ☐ Undergraduate Student

3. Typed name of co-principal investigator(s) — Date — Signature of co-principal investigator(s)

_____ _____

_____ _____

3a. Co-Principal investigator(s) (check all that apply)
☐ Faculty ☐ Staff ☐ Postdoctoral ☐ Graduate Student ☐ Undergraduate Student

3b. Typed name of major professor or supervisor (if not a co-principal investigator) — Date — Signature of major professor or supervising faculty member

_____ _____

4. Typed names of other key personnel who will directly interact with human subjects. (all key personnel must have training before approval will be made)
   Cynthia Shriver

5. Project (check all that apply)
   ☒ Research ☒ Thesis or dissertation ☐ Class project ☐ Independent Study (490, 590, Honors project)

6. Number of subjects (complete all that apply)
   up to 12 # adults, non-students up to 12 # ISU students _____ # other (explain)

   _____ # minors under 18 (must obtain assent from minor & parental consent)

7. Status of project submission through Office of Sponsored Programs Administration (check one)
   ☐ Has been submitted ☐ Will be submitted ☒ Will not be submitted

7a. Funding Source: The tests are being conducted in The Sensory Evaluation Unit of the Center for Designing Foods to Improve Nutrition . The Center will be reimbursed for the costs associated with running the sensory tests by the personnel in the Department of Animal Science who requested the tests.

7b. Title of grant as listed on the Proposal Data Form (GoldSheet) if it differs from title above: _____

8. Brief description of proposed research involving human subjects: (See instructions, item **(Include one copy of the complete proposal if submitting to a Federal sponsor.)**

   We are running the sensory tests at the request of Jay Wenther, a graduate student in the Department of Animal Science. The eight frankfurter formulations to be tested will be prepared in the ISU Meats Laboratory as a part of a research project being conducted by Mr. Wenther. The processing will be conducted in the same way as if the products were being made for retail sale, under the Fully Cooked, Not Shelf Stable Meat Products HACCP plan. The processed products will be delivered to the Sensory Evaluation Unit in the Center for Designing Foods to Improve Nutrition where the sensory testing will be conducted. All panelist recruitment, training and sensory testing will be conducted in the Sensory Analysis Unit of the Center for Designing Foods to Improve Nutrition by Jane Love and Cynthia Shriver. Ten - 12 volunteers will be sought for a panel to determine the textural characteristics of frankfurters. We will seek volunteers from people who have previously participated in similar tests. The panel will be trained to conduct these types of evaluations in three one-hour sessions, then will participate in one test per week (each test will require about 20-30 minutes of time) for each of the three subsequent weeks. All of the contacts with the panelists will be by the personnel listed on this form. Before the sensory data is provided to Mr.Wenther, all panelist identifiers will be removed.

9. Informed Consent:
   - ☒ Signed informed consent will be obtained. **(Attach a copy of your form.)**
   - ☐ Modified informed consent will be obtained. **(Attach a copy of your letter.)**

10. Confidentiality of Data: Describe below the methods you will use to ensure the confidentiality of data obtained. (See instructions, item 10.)

    Panelists will be assigned an identifier code to be used on the sensory ballots where they record their perceptions of the texture of the products. No information about the panelists will be collected and their names will not be used in any publications or reports resulting from the project.

11. Will subjects in the research be placed at risk or incur discomfort? Describe any risks to the subjects and precautions that will be taken to minimize them. (The concept of risk goes beyond physical risk and includes risks to subjects' dignity and self-respect as well as psychological or emotional risk. See instructions, item 11.)

    There will be no risks or discomforts associated with consuming the products. A list of all ingredients in the products will be supplied to any potential volunteers, so that if they do not wish to consume any of the components of the products, they can decline to participate in the tests.

12. **CHECK ALL** of the following that apply to your research:
    - ☐ A. Medical clearance necessary before subjects can participate
    - ☒ B. Administration of substances (foods, drugs, etc.) to subjects
    - ☐ C. Physical exercise or conditioning for subjects
    - ☐ D. Samples (blood, tissue, etc.) from subjects mental health facilities, prisons, etc.)
    - ☐ E. Administration of infectious agents or recombinant DNA
    - ☐ F. Application of external stimuli
    - ☐ G. Application of noxious or potentially noxious stimuli institution or agency (attach letters of approval)
    - ☐ H. Deception of subjects
    - ☐ I. Subjects under 17years of age
    - ☐ J. Subjects in institutions (nursing homes,
    - ☐ K. Pregnant women
    - ☐ L. Research must be approved by another

If you checked any of the items in 12, please complete the following in the space below (include any attachments):

Items A-G Describe the procedures and note the proposed safety precautions.
The products are being prepared in the ISU Meat Laboratory in the same manner that would be used if the products were being prepared for retail sale. The product treatments being tested contain various ingredients provided by Proliant, Inc. that are commercially available for meat applications. Several of the products are currently used for their water binding, emulsification and/or gelling capabilities. The chicken and turkey collagens that will be used are approved by the USDA as flavoring, but not as binders/extenders. The purpose

of this study is to determine the effectiveness of the collagens in order to seek approval from USDA for their use as binders/extenders. Collagen is currently listed as a GRAS ingredient. The frankfurters will be stored under refrigeration and prepared for the sensory panel by following recommended procedures.

Items D-E The principal investigator should send a copy of this form to Environmental Health and Safety, 118 Agronomy Lab for review.

Item H Describe how subjects will be deceived; justify the deception; indicate the debriefing procedure, including the timing and information to be presented to subjects.

Item I For subjects under the age of 18, indicate how informed consent will be obtained from parents or legally authorized representatives as well as from subjects.

Items J-K Explain what actions would be taken to insure minimal risk.

Item L Specify the agency or institution that must approve the project. If subjects in any outside agency or institution are involved, approval must be obtained prior to beginning the research, and the letter of approval should be filed.

Iowa State University Human Subjects Review Form

OFFICE USE ONLY	
EXPEDITED _____	FULL
COMMITTEE _____	ID#_____

PI Last Name Love **Title of Project** Sensory Assessment of the Textural Characteristics of Frankfurters

Checklist for Attachments

The following are attached (please check):

13. ☐ Letter or written statement to subjects indicating clearly:
    a) the purpose of the research & a statement that the study involves research
    b) the use of any identifier codes (names, #'s), how they will be used, and when they will be removed (see item 18)
    c) an estimate of time needed for participation in the research
    d) if applicable, the location of the research activity
    e) how you will ensure confidentiality
    f) in a longitudinal study, when and how you will contact subjects later
    g) that participation is voluntary; nonparticipation will not affect evaluations of the subject
    h) contact information of the P.I. and if a student project, the major professor or supervising faculty member's contact information
14. ☒ A copy of the consent form (if applicable)
15. ☐ Letter of approval for research from cooperating organizations or institutions (if applicable)
16. ☐ Data-gathering instruments
17. ☐ Recruitment fliers or any other documents the subjects will see

18. Anticipated dates for contact with subjects. If using secondary data, the start date will be when the PI has access to and starts to use the data. Allow at least two weeks for review of your proposal before your anticipated start date.

First contact	**Last contact**
12/02/02	04/30/03
Month/Day/Year	Month/Day/Year

19. If applicable: anticipated date that identifiers will be removed from completed survey instruments and/or audio or visual tapes will be erased:

Not applicable
Month/Day/Year

20. Signature of Departmental Executive Officer	Date	Department or Administrative Unit
_____	_____	_____

If the PI or co-PI is also the DEO, a Dean signature authority must sign here.

21. Initial action by the Institutional Review Board (IRB):

☐ Project approved ☐ Pending Further Review _____ Date ☐ Project not approved _____ Date

☐ No action required _____ Date

22. Follow-up action by the IRB:

Project approved ☐ Project not approved _____ Date Project not resubmitted _____ Date

Rick Sharp	_____	_____
IRB Chairperson	Signature of IRB Chairperson	Date

Informed Consent Form

You are being asked to volunteer to evaluate the textural attributes of frankfurters. There will be no risks or discomforts to you as a result of participation in this project. All of the components of the samples that you would be asked to taste are listed on the attached sheet. If you do not wish to taste any of these components, you should excuse yourself from the study.

You will be asked to participate in three training sessions; each session will require approximately one hour of your time. After training you will be asked to participate in three product-testing sessions: each session will require about 20-30 minutes. All training and test sessions will be held in the Sensory Evaluation laboratory located in Room 1121 in the Human Nutritional Sciences Building.

You will be asked not to eat, drink anything except water, chew gum or smoke for one hour before each tasting session and to avoid using perfumes or other products with strong fragrances before the test sessions.

You may ask questions about the project at any time. You will be given a copy of this form and you are free to withdraw from the project at any time by sending a notice to the principal investigator at the campus address or email address given below.

Project participants will be assigned a numerical code; this code will be used to identify the data that we collect from you. We will never refer to individual participants by name in any publications or presentations that result from the studies.

If you agree to participate in the study, sign and date as indicated below. Your signature indicates that you have read and understood this document and that you have asked and had answered any questions that you had about the study.

Please print your name_____

Please sign your name_____

Date_____

Jane A. Love
Principal Investigator
1117 Human Nutritional Sciences Building
Iowa State University
Phone: 515-294-4361
email: jlove@iastate.edu

Ingredient List

The products to be tested may contain the following ingredients:

Lean pork
Pork fat
Ice
Water
Frankfurter seasoning (blend of dextrose, mustard, spices, garlic powder)
Salt
Sodium phosphate
Sodium erythorbate
Sodium nitrite
Spray-dried beef plasma
Dehydrated pork fatty tissue
Pork collagen
Chicken flavor
Turkey flavor
Partially hydrolyzed whey protein concentrate

Appendix 18: Commercial Products used for Sensory Panelist Training

To determine the initial texture characteristics of the commercial products, samples were subjected to texture analysis. Puncture analysis was completed as described in Appendix 11 and compression analysis was performed as described in Appendix 12.

Puncture Analysis

Product	Peak Force (gm of force)	Internal Force (gm of force)
Hormel Vienna Sausage	94.5	56.7
Armor Stars Hot Dogs – Original	301.5	158.1

Texture Analysis

Product	Cohesiveness	Chewiness (gm of force)	Springiness (mm of distance)	Hardness (gm of force)
Gerber Graduate Meat Sticks	0.21	1821.5	10.7	1133.0
Armor Stars Hot Dogs – Original	0.65	4175.9	15.1	8178.9
Hormel Fat-Free Beef Hot Dogs	0.62	4241.0	17.5	2473.3
Jack Link's Original Beef Stick	0.51	41410.0	17.4	1083.0

Appendix 19: Commercial Products used to obtain a Wide Range of Puncture and Texture Characteristics

To determine what products would be beneficial to use in the training of the sensory panelist, numerous commercial frankfurters were purchased and subjected to texture analysis. Puncture analysis was completed as described in Appendix 11 and compression analysis was performed as described in Appendix 12.

Puncture Analysis

Product	Peak Force (gm of force)	Internal Force (gm of force)
Armor Star – Beef	534.0	241.3
Armor Star – Original	301.5	158.1
Butterball – Lean	481.8	212.1
Dubuque – Beef (Plumper size)	438.4	172.3
Dubuque – Extra Lean (Plumper size)	315.7	139.3
Dubuque – Original (Plumper size)	327.4	160.1
Farmland – Original	212.8	101.1
Gerber Graduates – Chicken	141.2	119.9
Gerber Graduates – Meat Sticks	189.4	137.5
Hormel – Beef (Fat Free)	199.1	93.9
Hormel – Vienna Sausage	94.5	56.7
ISU Meat Laboratory – Coarse	630.3	241.2
ISU Meat Laboratory – Fine	589.4	207.4
Louis Rich – Turkey (Original)	318.3	111.9
Oscar Mayer – Beef (Light)	373.7	172.5
Yves – Veggie Dogs	252.1	184.5

Texture Analysis

Product	Cohesiveness	Chewiness (gm of force)	Springiness (mm of distance)	Hardness (gm of force)
Armor Star – Beef	0.50	61320.7	14.7	9096.8
Armor Star – Original	0.65	48223.3	15.1	8178.9
Butterball – Lean	0.58	55616.2	17.4	4030.2
Dubuque – Beef (Plumper size)	0.54	43337.0	13.2	7172.0
Dubuque – Extra Lean (Plumper size)	0.67	37695.8	16.7	7384.3
Dubuque – Original (Plumper size)	0.65	61595.4	16.2	7457.9
Farmland – Original	0.64	26702.1	14.9	2651.3
Gerber Graduates – Chicken	0.18	2450.4	11.3	974.5
Gerber Graduates – Meat Sticks	0.21	1821.5	10.7	1133.0
Hormel – Beef (Fat Free)	0.62	27824.8	17.5	2473.3
Hormel – Vienna Sausage	0.28	3982.7	15.1	1141.8
ISU Meat Laboratory – Coarse	0.52	62011.3	16.1	6423.3
ISU Meat Laboratory – Fine	0.63	68905.4	15.3	9155.3
Oscar Mayer – Beef (Light)	0.29	17148.3	16.9	4476.8
Yves – Veggie Dogs	0.68	44165.6	15.7	7985.6

Appendix 20: Description of Terms used for Sensory Evaluation Frankfurters

Attributes, Techniques, and End-Point Labels

Term	Technique	Label for 0	Label for 15	Reference and Values
Toughness of exterior	Place the sample between the incisors so that you will be able to bite through the skin. Bite down evenly, and evaluate the force to penetrate through the surface	Very soft	Very tough	Hormel Vienna Sausage Value = 1 Armour Stars Hot Dogs - Original Value = 11
Hardness	Place the sample between your molars as described above, bite down evenly, and evaluate the force to bite completely through the sample.	Very soft	Very hard	Gerber Graduate Meat Stcks Value = 1 Armour Stars Hot Dogs - Original Value = 10
Cohesiveness	Place the sample between your molars as described above, compress it fully and evaluate the degree to which the sample deforms before it ruptures. A sample with high cohesiveness will undergo much deformation before it ruptures. A sample with low cohesiveness ruptures with little deformation.	Not cohesive (little deformation before rupture)	Very cohesive (much deformation before rupture)	Jack Link's Original Beef Stick Value = 1

Attributes, Techniques, and End-Point Labels

Term	Technique	Label for 0	Label for 15	Reference and Values
Springiness	Place the sample between your molars, with the cut edges adjacent to the surface of the molars. Compress partially without breaking, release, and evaluate the degree to which the sample returns to its original shape.	Not springy	Very springy	Gerber Graduate Meat Sticks Value = 1 Hormel Fat-Free Beef Hot Dogs Value = 10
Chewiness	The amount of chewing required to prepare the sample for swallowing.	Not chewy	Very chewy	Gerber Graduate Meat Sticks Value = 2 Armour Stars Hot Dogs - Original Value = 9
Juiciness	The progressive increase in the sensation of moisture in the mouth during chewing	Not juicy	Very juicy	No Reference

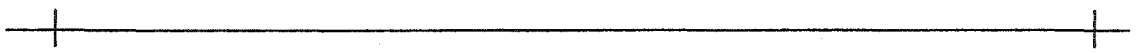
Appendix 21: Sensory Evaluation Score Sheet for Frankfurters

Sensory Evaluation Score Sheet for Frankfurters

Date _____
ID _____
Sample Code _____

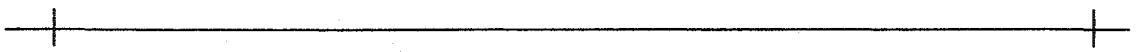
Please make a horizontal mark on each line to indicate your perception of the textural attributes of the sample.

Toughness: Place the sample between the incisors so that you will be able to bite through the skin. Bite down evenly, and evaluate the force to penetrate through the surface



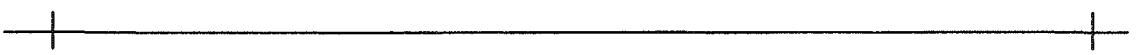
Very soft Very tough

Hardness: Place the sample between your molars as described above, bite down evenly, and evaluate the force to bite completely through the sample.



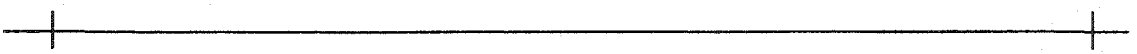
Very soft Very hard

Cohessiveness: Place the sample between your molars as described above, compress it fully and evaluate the degree to which the sample deforms before it ruptures. A sample with high cohesiveness will undergo much deformation before it ruptures. A sample with low cohesiveness ruptures with little deformation.



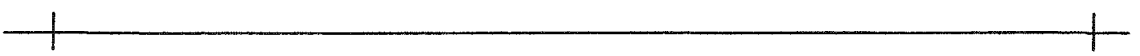
Not cohesive Very cohesive

Springiness: Place the sample between your molars, with the cut edges adjacent to the surface of the molars. Compress partially without breaking, release, and evaluate the degree to which the sample returns to its original shape.



Not springy Very springy

Chewiness: Place sample between molars and evaluate the amount of chewing required to prepare the sample for swallowing.



Not chewy Very chewy

Juciness: The progressive increase in the sensation of moisture in the mouth during chewing

Not juicy Very juicy

Appendix 22: Consumer Sensory Evaluation Score Sheet for Frankfurters Containing Poultry Protein Ingredients

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Consumer Sensory Evaluation Score Sheet for Frankfurters

Date _____

Registration Code _____

Please answer all questions. Your name is not on the questionnaire and will not be identified with your answers.

1. What is your age?

18-24 _____
25-34 _____
35-44 _____
45-54 _____
55-64 _____
>64 _____

2. What is your gender?

male _____
female _____

3. How often do you typically consume frankfurters?

once a week or more _____
at least once a month _____
a few times per year _____
only rarely_____
never_____

Please rinse your mouth with water before starting the test. Choose the numbered container listed first on the ballot. Open the container and taste the sample. Indicate your overall opinion of the sample. Rinse your mouth with water again and proceed to the next sample listed on the ballot. Repeat the process until you have evaluated all of the samples.

Code Number _____

dislike extremely	neither like or dislike	like extremely

Comments: _____

_____

_____

Appendix 23: SAS Programs for Phase 1 – Preliminary Model Emulsion System

Rao PV. 1998. Single factor studies: Comparing means and determining sample sizes. In: Statistical Research Methods in the Life Sciences. Pacific Grove, CA: Brooks/Cole Publishing Co. P326-377.

SAS Institute, Inc. 2001. SAS user's guide, version 8.2. SAS Institute. Cary, NC.

Processing SAS Program

This program was design to analyze processing parameters: tube yield, water separation, fat separation, hot yield, raw emulsion pH and cooked sample pH. Significant ($P<0.05$) main effects were analyzed. Least squares means was used to separate the means. Significant main effects were separated using the Bonferroni adjusted p-value method in which the original p-value was multiplied by the number of comparisons made (e.g. 14 comparisons within each treatment percentage group) (Rao 1998.).

```
Proc sort;
      by trtmnt;
      Run;
Proc glm;
      class rep trtmnt;
      model yield watersep fatsep hotyield rawph cookph = rep
            trtmnt;
      lsmeans trtmnt/pdiff stderr;
      Run;
```

Proximate Composition SAS Program

This program was design to analyze proximate composition parameters: moisture, fat, protein, and ash. Significant ($P<0.05$) main effects were analyzed. Least squares means was used to separate the means. Significant main effects were separated using the Bonferroni adjusted p-value method in which the original p-value was multiplied by the number of comparisons made (e.g. 14 comparisons within each treatment percentage group) (Rao 1998.).

```
Proc sort;
      by trtmnt;
      Run;
Proc glm;
      class rep trtmnt;
      model moisture fat protein ash = rep trtmnt;
      lsmeans trtmnt/pdiff stderr;
      Run;
```

Puncture Test SAS Program

This program was design to analyze puncture test parameters: peak force and internal force. The data was analyzed in two ways: (1) determine the effect of the treatments within sample type (i.e. centrifuge tube samples, cellulose casing samples with skin on – frankfurter-skin on, and cellulose casing samples with the skin off – frankfurter-skin off); and (2) determine the effect of sample type within each treatment. Significant ($P<0.05$) main effects were analyzed. Least squares means was used to separate the means. Significant main effects were separated using the Bonferroni adjusted p-value method in which the original p-value was multiplied by the number of comparisons made (e.g. 14 comparisons within each treatment percentage group) (Rao 1998.).

The effect of the treatments within sample type

```
Proc sort;
      by type;
      Run;
Proc glm;
      class rep trtmnt type;
      model pforce iforce = rep trtmnt type type*trtmnt;
      lsmeans trtmnt/pdiff stderr;
      by type;
      Run;
```

Texture Test SAS Program

This program was design to analyze texture test parameters: cohesiveness, chewiness, springiness, and hardness 1 (first bite). The data was analyzed in two ways: (1) determine the effect of the treatments within sample type (i.e. centrifuge tube samples, core samples from centrifuge tube cellulose casing samples with skin on – frankfurter-skin on, and cellulose casing samples with the skin off – frankfurter-skin off); and (2) determine the effect of sample type within each treatment. Significant ($P<0.05$) main effects were analyzed. Least squares means was used to separate the means. Significant main effects were separated using the Bonferroni adjusted p-value method in which the original p-value was multiplied by the number of comparisons made (e.g. 14 comparisons within each treatment percentage group) (Rao 1998.).

The effect of the treatments within sample type

```
Proc sort;
      by type;
      Run;
Proc glm;
      class rep trtmnt type;
      model cohess chewi spring hard1 = rep trtmnt type
            type*trtmnt;
      lsmeans trtmnt/pdiff stderr;
      by type;
      Run;
```

Appendix 24: SAS Programs for Phase 2 – Model Emulsion System

Rao PV. 1998. Single factor studies: Comparing means and determining sample sizes. In: Statistical Research Methods in the Life Sciences. Pacific Grove, CA: Brooks/Cole Publishing Co. P326-377.

SAS Institute, Inc. 2001. SAS user's guide, version 8.2. SAS Institute. Cary, NC.

Processing SAS Program

This program was design to analyze processing parameters: tube yield, water separation, fat separation, raw emulsion pH and cooked sample pH. Significant ($P<0.05$) main effects were analyzed. Least squares means was used to separate the means. Significant main effects were separated using the Bonferroni adjusted p-value method in which the original p-value was multiplied by the number of comparisons made (e.g. 5 comparisons within each treatment percentage group) (Rao 1998.).

```
Proc sort;
      by trtmnt;
      Run;
Proc glm;
      class rep trtmnt;
      model yield watersep fatsep rawph cookph = rep trtmnt;
      lsmeans trtmnt/stderr;
      Run;
```

Proximate Composition SAS Program

This program was design to analyze proximate composition parameters: moisture, fat, protein, and ash. Significant ($P<0.05$) main effects were analyzed. Least squares means was used to separate the means. Significant main effects were separated using the Bonferroni adjusted p-value method in which the original p-value was multiplied by the number of comparisons made (e.g. 5 comparisons within each treatment percentage group) (Rao 1998.).

```
Proc sort;
      by trtmnt;
      Run;
Proc glm;
      class rep trtmnt;
      model moisture fat protein ash = rep trtmnt;
      lsmeans trtmnt/pdiff stderr;
      Run;
```

Color Analysis SAS Program

This program was design to analyze color parameters: internal CIE L* (lightness), a* (redness/greenness) and b* (yellowness/blueness). The data was analyzed to determine the effect of the treatments within sample type (i.e. centrifuge tube samples). Significant ($P<0.05$) main effects were analyzed. Least squares means was used to separate the means. Significant main effects were separated using the Bonferroni adjusted p-value method in which the original p-value was multiplied by the number of comparisons made (e.g. 5 comparisons within each treatment percentage group) (Rao 1998.).

The effect of the treatments within sample type

```
Proc sort;
      by type;
      Run;
Proc glm;
      class rep trtmnt type;
      model l a b = rep trtmnt;
      lsmeans trtmnt/pdiff stderr;
      by type;
      Run;
```

Puncture Test SAS Program

This program was design to analyze puncture test parameters: peak force and internal force. The data was analyzed to determine the effect of the treatments within sample type (i.e. centrifuge tube samples). Significant ($P<0.05$) main effects were analyzed. Least squares means was used to separate the means. Significant main effects were separated using the Bonferroni adjusted p-value method in which the original p-value was multiplied by the number of comparisons made (e.g. 5 comparisons within each treatment percentage group) (Rao 1998.).

The effect of the treatments within sample type

```
Proc sort;
      by type;
      Run;
Proc glm;
      class rep trtmnt type;
      model pforce iforce = rep trtmnt type type*trtmnt;
      lsmeans trtmnt/pdiff stderr;
      by type;
      Run;
```

Texture Test SAS Program

This program was design to analyze texture test parameters: cohesiveness, chewiness, springiness, and hardness 1 (first bite). The data was analyzed to determine the effect of the treatments within sample type (i.e. centrifuge tube samples). Significant ($P<0.05$) main effects were analyzed. Least squares means was used to separate the means. Significant main effects were separated using the Bonferroni adjusted p-value method in which the original p-value was multiplied by the number of comparisons made (e.g. 5 comparisons within each treatment percentage group) (Rao 1998.).

The effect of the treatments within sample type

```
Proc sort;
      by type;
      Run;
Proc glm;
      class rep trtmnt sample type;
      model cohess chewi spring hard1 = rep trtmnt type
            type*trtmnt;
      lsmeans trtmnt/pdiff stderr;
      by type;
      Run;
```

Appendix 25: SAS Programs for Phase 3 – Frankfurter System

SAS Institute, Inc. 2001. SAS user's guide, version 8.2. SAS Institute. Cary, NC.

Processing SAS Program

This program was design to analyze processing parameters: water separation, fat separation, smokehouse yield. Significant (P<0.05) main effects were analyzed. Least squares means was used to separate the means. For each processing parameter, treatments were compared to the control for similarity.

```
%let respvar = Y;          /* replace Y with name of response variable */
%let trtvar = TRT;         /* replace TRT with name of treatment variable */
%let block = REP;          /* replace REP with name of blocking variables */
                           /* leave blank (%let block = ;) if no blocks */

%let lower = ___;           /* replace ___ and ___ with the appropriate */
%let upper = ___;           /* bounds of the region considered equiv to 0 */
```

```
Proc glm;
   class &block &trtvar;
   model &respvar = &block &trtvar;
   lsmeans &trtvar /pdiff cl stderr alpha = 0.1;
   ods output LSMeanDiffCL = diffs;
   Run;

   data equiv;
   set diffs;

   if ((&lower  <= lowercl) and (uppercl  <= &upper)) then
   signif =  '*';
   else signif = ' ';

   ods listing select all;

Proc print label data = equiv;
   id dependent;
   var  effect i j difference signif;
   label i = 'Treatment';
   label j = 'With';
   label signif = 'Equiv. to 0?';
   Run;
```

Color Analysis SAS Program

This program was design to analyze color parameters: internal CIE L* (lightness), a* (redness/greenness) and b* (yellowness/blueness). The data was analyzed to determine the effect of the treatments within sample type (i.e. cellulose casing samples with skin on – frankfurter-skin on). Significant ($P<0.05$) main effects were analyzed. Least squares means was used to separate the means. For each puncture analysis parameter, treatments were compared to the control for similarity.

```
%let respvar = Y;          /* replace Y with name of response variable */
%let trtvar = TRT;         /* replace TRT with name of treatment variable */
%let block = REP;          /* replace REP with name of blocking variables */
                           /* leave blank (%let block = ;) if no blocks */

%let lower = ___;           /* replace ___ and ___ with the appropriate */
%let upper = ___;           /* bounds of the region considered equiv to 0 */
```

```
Proc glm;
   class &block &trtvar;
   model &respvar = &block &trtvar;
   lsmeans &trtvar /pdiff cl stderr alpha = 0.1;
   ods output LSMeanDiffCL = diffs;
   Run;

   data equiv;
   set diffs;

   if ((&lower  <= lowercl) and (uppercl  <= &upper)) then
   signif =  '*';
   else signif = ' ';

   ods listing select all;

Proc print label data = equiv;
   id dependent;
   var  effect i j difference signif;
   label i = 'Treatment';
   label j = 'With';
   label signif = 'Equiv. to 0?';
   Run;
```

Proximate Composition SAS Program

This program was design to analyze proximate composition parameters: moisture, fat, protein, and ash. Significant (P<0.05) main effects were analyzed. Least squares means was used to separate the means. For each proximate analysis parameter, treatments were compared to the control for similarity.

```
%let respvar = Y;          /* replace Y with name of response variable */
%let trtvar = TRT;         /* replace TRT with name of treatment variable */
%let block = REP;          /* replace REP with name of blocking variables */
                           /* leave blank (%let block = ;) if no blocks */

%let lower = ___;           /* replace ___ and ___ with the appropriate */
%let upper = ___;           /* bounds of the region considered equiv to 0 */
```

```
Proc glm;
   class &block &trtvar;
   model &respvar = &block &trtvar;
   lsmeans &trtvar /pdiff cl stderr alpha = 0.1;
   ods output LSMeanDiffCL = diffs;
   Run;

   data equiv;
   set diffs;

   if ((&lower  <= lowercl) and (uppercl  <= &upper)) then
   signif =  '*';
   else signif = ' ';

   ods listing select all;

Proc print label data = equiv;
   id dependent;
   var  effect i j difference signif;
   label i = 'Treatment';
   label j = 'With';
   label signif = 'Equiv. to 0?';
   Run;
```

Puncture Test SAS Program

This program was design to analyze puncture test parameters: peak force and internal force. The data was analyzed to determine the effect of the treatments within sample type (i.e. cellulose casing samples with skin on – frankfurter-skin on). Significant ($P<0.05$) main effects were analyzed. Least squares means was used to separate the means. For each puncture analysis parameter, treatments were compared to the control for similarity.

```
%let respvar = Y;          /* replace Y with name of response variable */
%let trtvar = TRT;         /* replace TRT with name of treatment variable */
%let block = REP;          /* replace REP with name of blocking variables */
                           /* leave blank (%let block = ;) if no blocks */

%let lower = ___;           /* replace ___ and ___ with the appropriate */
%let upper = ___;           /* bounds of the region considered equiv to 0 */
```

```
Proc glm;
   class &block &trtvar;
   model &respvar = &block &trtvar;
   lsmeans &trtvar /pdiff cl stderr alpha = 0.1;
   ods output LSMeanDiffCL = diffs;
   Run;

   data equiv;
   set diffs;

   if ((&lower  <= lowercl) and (uppercl  <= &upper)) then
   signif =  '*';
   else signif = ' ';

   ods listing select all;

Proc print label data = equiv;
   id dependent;
   var  effect i j difference signif;
   label i = 'Treatment';
   label j = 'With';
   label signif = 'Equiv. to 0?';
   Run;
```

Texture Test SAS Program

This program was design to analyze texture test parameters: cohesiveness, chewiness, springiness, and hardness 1 (first bite). The data was analyzed to determine the effect of the treatments within sample type (i.e. cellulose casing samples with skin on – frankfurter-skin on). Significant ($P<0.05$) main effects were analyzed. Least squares means was used to separate the means. For each puncture analysis parameter, treatments were compared to the control for similarity.

```
%let respvar = Y;          /* replace Y with name of response variable */
%let trtvar = TRT;         /* replace TRT with name of treatment variable */
%let block = REP;          /* replace REP with name of blocking variables */
                           /* leave blank (%let block = ;) if no blocks */

%let lower = ___;           /* replace ___ and ___ with the appropriate */
%let upper = ___;           /* bounds of the region considered equiv to 0 */
```

```
Proc glm;
   class &block &trtvar;
   model &respvar = &block &trtvar;
   lsmeans &trtvar /pdiff cl stderr alpha = 0.1;
   ods output LSMeanDiffCL = diffs;
   Run;

   data equiv;
   set diffs;

   if ((&lower  <= lowercl) and (uppercl  <= &upper)) then
   signif =  '*';
   else signif = ' ';

   ods listing select all;

Proc print label data = equiv;
   id dependent;
   var  effect i j difference signif;
   label i = 'Treatment';
   label j = 'With';
   label signif = 'Equiv. to 0?';
   Run;
```

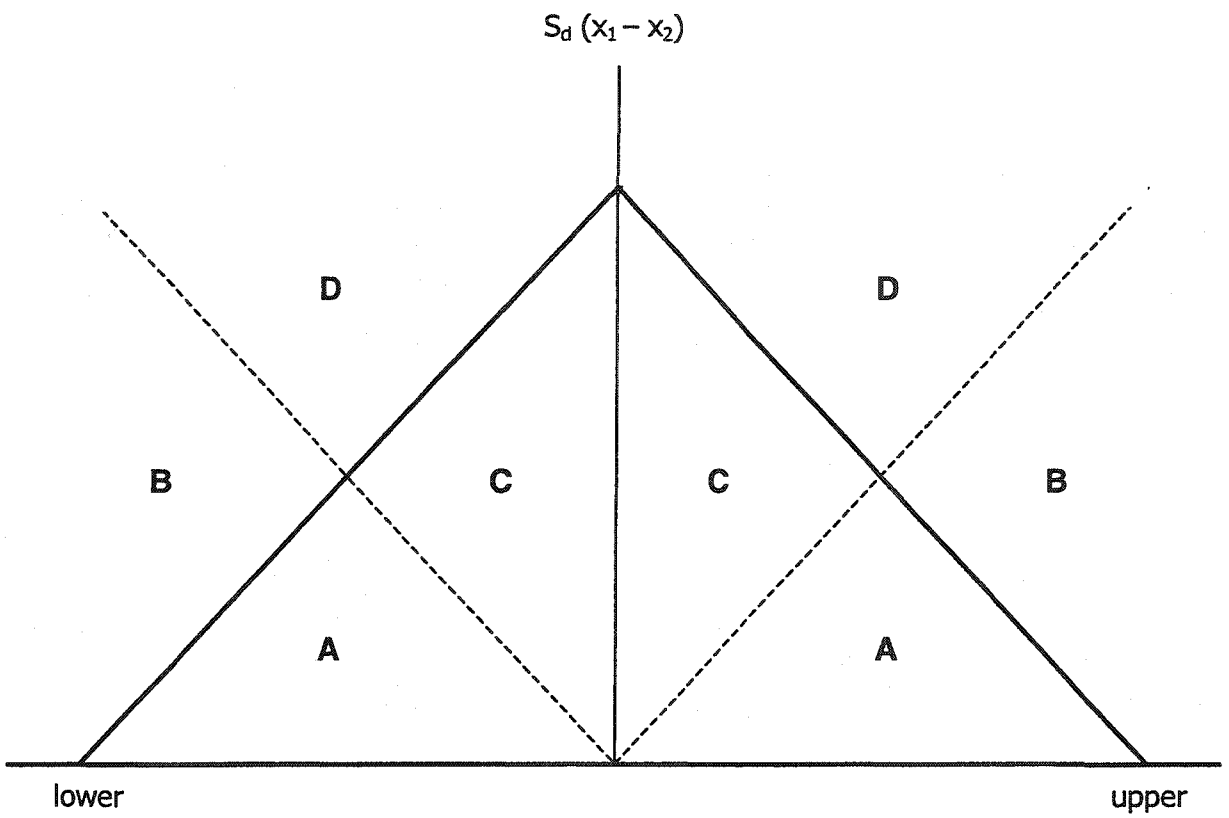
Sensory Analysis SAS Program

This program was design to analyze color parameters: toughness, hardness, cohesiveness, springiness, chewiness, and juiciness. The data was analyzed to determine the effect of the treatments within sample type (i.e. cellulose casing samples with skin on – frankfurter-skin on). Significant ($P<0.05$) main effects were analyzed. Least squares means was used to separate the means. For each puncture analysis parameter, treatments were compared to the control for similarity.

```
%let respvar = Y;          /* replace Y with name of response variable */
%let trtvar = TRT;         /* replace TRT with name of treatment variable */
%let block = REP;          /* replace REP with name of blocking variables */
                           /* leave blank (%let block = ;) if no blocks */

%let lower = ___;           /* replace ___ and ___ with the appropriate */
%let upper = ___;           /* bounds of the region considered equiv to 0 */
```

```
Proc glm;
   class &block &trtvar;
   model &respvar = &block &trtvar;
   lsmeans &trtvar /pdiff cl stderr alpha = 0.1;
   ods output LSMeanDiffCL = diffs;
   Run;

   data equiv;
   set diffs;

   if ((&lower  <= lowercl) and (uppercl  <= &upper)) then
   signif =  '*';
   else signif = ' ';

   ods listing select all;

Proc print label data = equiv;
   id dependent;
   var  effect i j difference signif;
   label i = 'Treatment';
   label j = 'With';
   label signif = 'Equiv. to 0?';
   Run;
```

Appendix 26: Schematic to Determine Difference and/or Equivalence Between the Treatments and the Control



Letter	Standard Error	Difference (Control average - treatment average)	Test of u = 0	Equivalence	Result
A	Small	Moderate	Reject	Yes	Different Equivalent
B	Small	Large	Reject	No	Different Not equivalent
C	Moderate	Small	Accept	Yes	Not different Equivalent
D	Large	Small - Large	Accept	No	Not different Not equivalent